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Prediction of Naso-labial Morphology from Dental Pattern Assessments

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Prediction of Naso-labial Morphology from Dental Pattern Assessments

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Declaration

I hereby declare that the following thesis is based on the results of investigations conducted by me, and that this thesis is of my own composition. Work other than my own is clearly indicated in the text by reference to the relevant researchers or their publications. No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university, or other institute of learning.

Signed……………………………………………………Date…...……………………………

Amal Albtoosh

I certify that the work of which this thesis is a record was performed by Amal Albtoosh. The conditions of the relevant Ordinance and Regulations have been fulfilled.

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Professor Caroline M Wilkinson

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Professor Peter A Mossey

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List of Abbreviation

A-A'	**Upper Lip Thickness**
ANS	Anterior Nasal Spine
B-B'	Lower Lip Thickness
BMI	Body Mass Index
CFR/A	Craniofacial Reconstruction/Approximation
CM-Sn-Ls	Naso-Labial Angle
DNA	Deoxyribonucleic Acid
GMM	Geometric Morphometric
LAFH	Lower Anterior Facial Height
LI/MP	Lower Incisor Axis To Mandibular Plane Angle
N'-Pr-Pog'	Total Soft Tissue Convexity
N'-Sn-Pog'	Soft Tissue Convexity
PCA	Principle Component Analysis
PFH	Posterior Facial Height
Pog-Pog'	Soft Tissue Chin Thickness
Pr-A'	Nose Depth
Sti-Me'	Lower lip length
Sts-Sn	Upper lip length
TFH	Total Facial Height
UAFH	Upper Anterior Facial Height
UI/LI	Inter-Incisal Angle
UI/MX	Upper Incisor Axis to Maxillary Plane Angle

Glossary

Dental pattern: the terms dental pattern, skull shape and skeletal morphology are used interchangeably in this thesis. During the selection of cases for the study the focus was on incisor classification but participants with minimal or normal skeletal malocclusion were also included.

Depiction: a term employed recently to describe the final outcome of reconstruction or approximation.

Foil comparison: “something or someone that makes another’s good or bad qualities more noticeable” (Cambridge Dictionaries Online, 2016). Therefore, in some studies employed to assess the success rate of reconstruction this technique was used to contrast one reconstruction with another in order to highlight the resemblance rate of the outcomes.

Fulcrum point: a cephalometric landmark that forms with another point a cephalometric plane. These landmarks are defined in Table 3-1.

Level of chance: the level that the researcher would expect by random choices.

Lip fullness: this term was used to assess the amount of pigmented area of anatomical lips using the profile view photograph.

Lip thickness: this measured in the upper and lower lip width in anterior-posterior plane using cephalometric landmarks.

Naso-labial area: defined as the area “of, relating to, located between, or affecting the nose and the upper lip” (Evans, 2014). However, in this study, the vermillion border shape, lower lip and soft chin were studied along with the naso-labial area. Therefore, the term naso-labial was used to describe the studied area.

Abstract

This project aims to develop standards to predict vermillion border shape and appearance-i.e. the outline of the vermillion border and the fullness of lips, based on assessment of an individual dental pattern using a combination of three methods: morphological, cephalometric and GMM. This study tests a hypothesis that the skeletal and dental pattern in antero-posterior and vertical dimensions and the upper and the lower incisor inclinations can predict the morphology of the soft tissue of the lips. This hypothesis was examined by analysing retrospective facial data, which consists of two-dimensional, pre-orthodontic treatment photographs and cephalograms of individuals of four malocclusion classes: Class I, Class II: divisions 1 and 2, and Class III from two sample populations: 56 Scottish and 56 Jordanians, aged 11-14 years. All the Scottish participants had been recipients of treatment at the Dental Hospital at the University of Dundee, and the Jordanian sample were selected from the Orthodontic archive held by Jordan University Hospital.

The results reveal that a cephalogram analysis offers a statistically significant correlation differing from one type of malocclusion to another, in addition, analysis of cephalograms showing the value of angles and linear dimensions differed from one type of malocclusion to another. Photographic analysis using GMM afforded a statistically reliable correlation between naso-labial traits, and particularly between the vermillion border outline and malocclusion patterns. Due to their shared ancestry (Caucasian), both Jordanian and Scottish populations showed the same morphological trends for the lips, for example: long lower facial height, a deep philtrum, V-shaped Cupid's bow, thin upper vermillion border. GMM results suggest that vermillion border variation could be computed, at least when distinguishing between malocclusion classes from the same ethnic group. Morphological, GMM, and cephalograms analyses confirmed that the shape and diversity in the vermillion

border outline differed between malocclusion classes, but few or no differences could be shown between the sexes.

Chapter 1
Introduction

1.1 Introduction

This research aims to develop standards for the prediction of naso-labial appearance from skull shape and dental pattern. The ability to predict facial appearance is important for forensic identification and archaeological investigation. Existing approaches are compromised by a lack of sufficient data about the relationships between skull and facial appearance. Finding the best way to predict facial appearance from skull shape is a significant research challenge, requiring input from a range of disciplines including forensic anthropology, radiology, and orthodontics.

This research benefits from human head photographic and radiographic images collected at two Dental Schools in two countries, in order to establish relationships between dental pattern and feature morphology.

This study consists of six chapters. Chapter one focuses on background and literature reviews of the main subjects of this study: the history of forensic craniofacial reconstruction and previous studies on naso-labial morphology and dental pattern. Moreover, as this research will concentrate on the dental pattern in relation to occlusion and incisor relationship to establish any relationships between lip shape and nasal shape, the anatomy of the oral region and malocclusion classes will be discussed. While chapter two will review the related studies and literature that suggest the need for further forensic reconstruction standards to depict the naso-labial morphology from skull and dental pattern.

The following chapters describe the photographic and cephalometric analysis of living subjects using a number of different approaches to enable the appropriate prediction of nasolabial morphology.

This research will benefit the fields of biometrics and physical anthropology where analysis of population variation currently relies upon outdated and limited data.

Reliable and reproducible anatomical standards will be of great benefit to human identification for disaster victims, mass graves and forensic scenes of crime investigations, enabling faster and less time-consuming police investigations.

The creation of anatomical facial norms for different ethnic groups, sexes, statures, ages, and malocclusion classes will be useful as templates within the fields of maxillofacial surgery, orthodontics and plastic surgery where surgical intervention is employed to create "normality". In addition the ability to predict facial appearance from skeletal structure will be important following facial surgery and in relation to growth prediction for dental abnormalities and orthodontic surgery.

1.2 Aims and Objectives

1.2.1 Aims

The aims of this study are:

- To establish the relationship between malocclusion class and naso-labial morphology.
- To investigate and quantify the correlation of a variety of features of the lips to build up a typical morphological profile for different malocclusion classes.
- To develop a comprehensive approach to predict the naso-labial morphology, especially the vermillion border, from dental pattern.

1.2.2 Objectives

This study will be based on the following objectives as the guiding factors throughout the study:

- ❖ To analyze retrospective facial data (radiographs and photographs) in order to establish any relationship between lip shape and dental pattern using a combination of three methods: morphological, cephalometric and GMM.
- ❖ To establish the effects of age, sex and country of origin on lip shape.
- ❖ To develop a procedure to improve prediction of lip morphology for use in facial reconstruction from dental pattern.

1.3 Background of Facial Depiction from Skeletal Remains

Craniofacial reconstruction (CFR) or approximation (CFA) is fundamentally the depiction of the facial features from skeletal remains using a combination of different disciplines: osteology, artistry, anatomy, anthropology and forensic science (Wilkinson, 2004).

There are two schools of thought in this field that are related to different approaches to facial depiction from skeletal remains. These approaches use the terms craniofacial approximation (CFA) (Gatliff & Snow, 1979; Taylor, 2001; Stephan & Henneberg, 2001; Stephan, 2003a), and craniofacial reconstruction (CFR) (Gerasimov, 1971; Prag & Neave, 1997; Wilkinson, 2004). CFA predicts a “facial type”, which relies on facial templates, skull proportions, and average tissue depths. CFA practitioners believe the resulting face may also apply to other skulls and that there may be more than one face for each skull. Others prefer the term craniofacial reconstruction (CFR), as it suggests an attempt at characteristic detail rather than a facial type. These practitioners believe that each skull is as unique as each individual face, and the soft tissue depth differ between different ages (Ferrario *et al*., 1995; Manhein *et al.*, 2000; Wilkinson, 2002; Tedeschi-Oliveira *et al*., 2009), sex (Ferrario *et al*., 1995; İşcan, 2005; Wilkinson, 2002), and ethnic group (De Greef *et al*., 2006; Tedeschi-Oliveira *et al*., 2009; Utsuno *et al*., 2010; Briers *et al*., 2015). Nevertheless, it is acknowledged that some features cannot yet be predicted from the skull, such as: BMI, hair colour and style, facial hair, eye colour, and many more “social features” such as glasses, ageing and expression that have a huge impact in the final reconstruction (Wilkinson, 2004). Despite of the differences between the two schools, most researchers (Claes *et al*., 2010, Wilkinson *et al.*, 2003, Rynn *et* al., 2010) agree that CFR/A is an investigative tool, to be used alongside other legally accepted identification methods, such as finger prints, dental and radiographic assessments, and DNA analysis.

The reconstruction/approximation of facial feature appearance is dependent on assessment of the skull shape and one of the areas where there is a paucity of standards for prediction is at the mouth and lips (Wilkinson *et al*., 2003; Stephan, 2003b). Therefore, the main goal of this project is to provide a comprehensive approach to the process of reconstructing the lip features in consideration of the assessment of dental pattern and skeletal morphology.

1.4 History of Facial Depiction from Skeletal Remains

Facial depiction from skeletal remains was initially developed by European anatomists (Welker, 1883; His, 1895; Kollmann & Buchly, 1898; Merkel, 1900; Eggeling, 1913), working alongside artists and sculptors. In 1895, Wilhelm His made the first attempts by employing soft tissue depth data that was collected using cadaveric facial penetration methods based on a small sample of 24 males and four females. The penetration method utilized a needle with a rubber stop to pierce the skin of the face at selected points until it touched the bone. His used these data and with assistance from a sculptor, Sefner, produced a portrait to prove that a skull found in Leipzig belonged to the German composer, Johan Sebastien Bach (His, 1895). Later Kollman, a Swiss anatomist, and Buchly, a sculptor, used the same soft tissue data to produce a facial reconstruction of a Neolithic female from the Au Vernier region in Switzerland (Kollmann & Buchly, 1898). These cases are considered to be the first scientific studies in facial depiction from skeletal remains (Wilkinson, 2004).

An archaeological specimen became a defining case in relation to the perceived accuracy of craniofacial approximation/reconstruction. A partial skeleton of the species Homo neanderthalensis was discovered in La Chappelle-aux-Saints, France in 1908 (Prag & Neave, 1997; Wilkinson, 2004). There were many attempts to rebuild the face of the Neanderthal skull by different anthropologists from America, Russia, Europe and elsewhere, and it was established that the outcomes were noticeably different (Prag & Neave, 1997; Wilkinson, 2004).

In 1912, Wilder, a US anthropologist, revealed that the major source of difference in CFA/CFR was artistic subjectivity regarding the details of the facial features (Wilder, 1912). The first recorded comparative study was produced by Von Eggeling (1913) and revealed differences in practitioner assessment with little similarity between the faces produced by different practitioners on the same skull (Eggeling, 1913). Gerasimov (1971) considered this experiment to be imperfect, because the sculptors obviously had not followed the tissue depth data, and had not understood the relationships between the skull and the facial soft tissues. Therefore the case of the skull at La Chappelle-aux-Saints and Von Eggeling's experiment led European researchers to cease work in facial depiction from skeletal remains for many years (Prag & Neave, 1997).

Stadtmuller and Zimmerman in the early 1920s carried out a similar experiment to Von Eggeling (Stadtmuller, 1922; Stadtmuller, 1923) using Kollman and Buchly's soft tissue depth data on the skulls of two men: a 17 years old and a 62 years old. The similarity to the ante mortem photographs was considered poor (Stadtmuller, 1922; Stadtmuller, 1923).

In 1935, Suk, the Czech scientist, stated that the CFA process was a fantasy and there were no firm interrelationships between facial and skull morphology at the feature level (Suk, 1935).

An important figure in forensic science was the Russian anthropologist, Mikhail Gerasimov, who is best known for developing a method of facial reconstruction, based on his own observations of comparative anatomy and anthropology (Gerasimov, 1971). He stated that the errors in facial depiction from skeletal remains were the consequence of “carelessness” on the part of the sculptors (Gerasimov, 1971). In his method, Gerasimov (1971) integrated the mean tissue depth data with the observed facial musculature patterns. The morphology of the reconstructed face was then based upon the skull morphology and the shape of skeletal tissue around muscle origin.

Gerasimov (1955) observed facial soft tissue depth patterns relating to the wave or folds of the bony profile. He claimed that widely varying bony profiles displayed more variable soft tissue depth especially over prominent bones in the midline sagittal profile of the face, axial and transverse planes. Gerasimov (1955, 1971) stressed the importance of treating the features of the whole face in harmony or a balanced way rather than focused on the details of the face separately. The perception of “latent correlation”, which is the morphology of any portion of the face is interrelated to the morphology of the face as one piece, this concept is confirmed by schemes of facial evolution and observations in orthodontics.

Therefore, Gerasimov reconstructed only the masseter and the temporalis muscles, while the reconstruction of other muscles of facial expression was carried out by the application of individualized soft tissue patterns to the skull. Accordingly, Gerasimov's technique is considered as a meshwork of strips of soft tissue over the skull applying the soft tissue depths in a distinctive pattern depending on the undulation of the specific skull in different planes (Gerasimov, 1955).

Gerasimov claimed 100% success when utilizing his principles on 12 cadaver heads from the mortuary at Moscow Medical Institute (Gerasimov, 1971). Gerasimov stated that almost all forensic cases carried out in his laboratory were successfully identified (Gerasimov, 1971). There has been controversy surrounding the reproducibility of the anatomical approaches to CFR. It has been proposed that Gerasimov might have changed/amended the forensic cases after identification (Tyrrell *et al.*, 1997). Gerasimov is alleged to have fashioned features such as the hairstyle depending on a statement from a police list of missing people (Gerasimov, 1971).

A US anatomist, Wilton Krogman, developed a CFA method during the 1940s based on mean soft tissue depth data at several skeletal landmarks. The first step was to build the facial surface to the level of the mean tissue depth indicators, as a mesh between the pegs. In this method, the sculptor considered the muscular anatomy indirectly, and then the superficial features were sculpturally improved to add realism to the face (Krogman & İşcan, 1986). This technique is employed extensively in U.S. forensic cases (Taylor, 2001). Well-known practitioners of this technique include forensic artist, Betty Pat Gatliff, and forensic anthropologist, Clyde Snow, who sometimes worked in partnership (Gatliff & Snow, 1979). Currently, experts analyze skull topographies, for instance dental and skeletal occlusion, to predict characteristic feature detail, such as lip shape (Krogman & İşcan, 1986; Wilkinson *et al.*, 2003; Stephan, 2003b), which is a core purpose of this study as well.

Some practitioners adopted a “combination” approach of CFR, such as the technique established by medical artist, Richard Neave in Manchester, UK (Prag & Neave, 1997), which referred to as Manchester method, this method taught and technologically advanced principally by Richard Neave (Prag & Neave, 1997) and Wilkinson (2004). In this scheme, average soft tissue depth data at anatomical landmarks are utilized as a guide, at the same time, the fundamental anatomy is reconstructed muscle-by-muscle depending on confined skull morphology and attachment marks. To transcribe the outlines of the face, the muscles of mastication and facial expression are separately reconstructed. The facial morphology is recreated anatomically, relating to the principles recommended by Gerasimov (Gerasimov, 1971). Neave recreated a face on a skull replica, made from the Computed Tomography (CT) data of an anonymous, live subject, and the resemblance was adequate for him to distinguish that person at the conference where the resulting face was displayed (Prag & Neave, 1997). The route of recognition was a close imitation to that of a forensic situation, since Neave was familiar with the recreated face, but the subject was unknown to him. In a forensic situation the familiarity would be the other way round (with the subject rather than the reconstruction), but otherwise the scenario was similar (Prag & Neave, 1997).

Stephan (2003a) stressed that the perfect morphological estimation of the majority of the facial muscles is impractical, as a result of the subtle form and great variability of the muscles of facial expression.

1.5 Computer Technology Applied to CFR/A

The application of computer technology can be divided into two distinctive classifications: (1) computer-assisted CFR/A, and (2) automated CFA.

1.5.1 Computer-Assisted CFR/A

This term applies to cases where photo-editing software is used to improve or enhance manual CFR/A (Ubelaker & O'Donnell, 1992). For instance, the 2D manual CFR/A appearance is improved using Adobe Photoshop® software. By using this technology the facial features and contours are enhanced using a databank of facial images. These images are manually selected following CFR/A guidelines, then applied to a still image of the CFR/A.

3D CFR methods, such as the Manchester method established by Neave (Prag & Neave, 1997), have been transformed by the use of 3D computer modelling software. Wilkinson *et al*. (2006) utilised a virtual modelling system with a haptic interface and this system has been shown to be capable of producing proficient results as they claimed that *"The majority of the surfaces of the facial reconstructions showed less than 2.5 mm error and 90% of the male face and 75% of the female face showed less than 5 mm error*."

Computer-assisted CFR has a number of advantages over clay-based CFR. One of these advantages is the facility to change the soft tissue layer to translucent, in order that the skull morphology and hard-soft surface interrelationships can be observed during the reconstruction. Secondly, the computer-assisted CFR offers easy tracking of the CFR. Thirdly, the system enables post-CFR improvement, such as the addition of hair and prosthetic eyes. Fourthly, this system is better for skull reassembly, since this system is non-invasive and there is no destruction of fragile skull fragments, in particular, archaeological remains which are easily damaged. Moreover, this system has other significant advantages over the traditional method, in that it is clean, easy to use, and fast plus data can be delivered and saved digitally. This system required the physical skull to be converted into a virtual image using a laser or CT scanner, which may be expensive. Conversely, the traditional method which replicated the skull by casting procedures is it required more expensive in regards to materials and require training and is a time consuming.

1.5.2 Automated CFR

In 1980s, University College London established the first automated computer system for forensic use (Arridge *et al.*, 1985). This system was based upon a system used in craniofacial surgery (Wilkinson, 2005).

After this early attempt to automate CFA, numerous studies have been carried out internationally to develop automated systems. Input data has been collected from different resources using video and laser scanning, such as: craniometric and cephalometric (Evison, 1996), MRI (Evison, 1996; Michael & Chen, 1996), and CT (Quatrehomme *et al*., 1997). Nevertheless, these systems are often "biased" and affected by the template choice (Claes *et al*., 2006), so that any resulting face will have a tendency to resemble the template face more than the individual. This problem occurs because many of the facial features remain unchanged and to solve this problem Claes *et al*. (2006) suggested that "*In the future, it is important to collect as much craniofacial data as possible for different populations of ancestry, age, gender and BMI. The visual and life-like quality of computer-based CFR results is dependent on the quality of the samples in the reference database*" (Claes *et al*., 2006). Vanezis *et al*. (2000) justified this technique by indicating that *"the prediction of the true morphology of soft tissue features such as the ears, nose, lips and eyes will remain largely speculative - at least for the foreseeable future."* (Vanezis *et al*., 2000).

Therefore the present research will attempt to improve the quality of these constructions by providing new data in the nasolabial area such as cephalometric measurements, morphological and GMM analysis and for populations: the Scottish and the Jordanian that have not been previously studied.

1.6 Accuracy of CFR/A

The accuracy of the methods of CFR/A has continuously been questioned. Quatrehomme *et al.* (2007) claimed that the greatest of the successes available in the literature and presented in media are "*single forensic cases of CFR*" and emphasize that resemblance may be "*poor*". However, the missing person could be recognized by a relative after the CFR was published in the media (Quatrehomme *et al*., 2007). The frequently utilized methods for the evaluation of CFR/A accuracy are: resemblance ratings, face pools, success rates, and morphometric assessment. Relevant literature relating to CFR/A will be discussed in the forthcoming paragraphs.

1.6.1 Resemblance Evaluation

Resemblance ratings are defined as an effort to calculate qualitative, subjective recognition when evaluating accuracy. A CFR/A outcome is compared to an ante mortem image of the subject and ranked for likeness; for example: strongly, closely, approximately, or no resemblance.

Helmer *et al.* (1993) used these categorizations to investigate the accuracy of his technique by using reconstructed skulls from previously solved forensic cases and comparing them to the relevant ante mortem facial images. Twelve skulls were reconstructed by two practitioners utilizing a method, based on previous research, including Kollman, Wilder, Stadtmuller, Krogman and Gerasimov (via his students Ullrich and Lebedinskaya). The method relied on soft tissue depth data and pattern, while the musculature was not recreated (Helmer *et al.*, 1993). The results of the reconstructions by the two practitioners on each skull were compared. These results were ranked as 33% close resemblance, and 50% approximate resemblance to each other. However, when comparing each reconstruction to the applicable ante mortem photograph, the result showed 38% close resemblance, 17% approximate resemblance and 42% slight resemblance (Helmer *et al.,* 1993). Therefore, it seems that the results were positive, even though the statistics indicated that the two sets of reconstructions were more like each other than the ante mortem image. These results indicated that the employed procedure was more reproducible than it was morphologically precise.

A small study was carried out by Wilkinson & Neave (2001) using a forensic case of a fire victim from 1997 brought by Staffordshire Police to University of Manchester. The outcome led to a positive recognition by a relative, and the reconstruction was assessed using resemblance ratings and ten members of the general public, who considered it to be a remarkable or very close (90%) resemblance to the victim (Wilkinson & Neave, 2001). Stephan (2000) emphasized that resemblance ratings were imperfect when he found that ‘true positives’ were equally rated to ‘false positives’ when compared to the same ante mortem image. Nevertheless, the incorrect ante mortem images to which the ‘false positives’ were compared were chosen from a face pool by unbiased observers who assumed them to be right. Consequently, each ‘false positive’ CFA self-evidently reminds you of the selection of incorrect ante mortem image more closely than the rest of the face pool, including the correct ante mortem image (Stephan, 2000).

Wilkinson and Whittaker (2002) used further factors for resemblance ratings, such as age, BMI, eyes, nose, mouth, chin and overall likeness, in an effort to apply the resemblance rating in a more detailed manner and to detect regions of morphological error. In this study a ‘foil’ assessment was also employed, where the reconstruction was compared to an arbitrarily chosen face pool of similar sex, age and ancestry to the correct individual. Results showed that the ‘foil’ rated significantly lower resemblance for all factors, excluding the age and the eyes (Wilkinson & Whittaker, 2002). According to Wilkinson (2004), one more problem associated with resemblance ratings technique, is that when the observers compare the reconstruction to the target there is tendency to look for errors rather than similarities (Wilkinson, 2004).

1.6.2 Face Pool Evaluation

To judge accuracy using the face pool recognition technique, a CFR/A is observed in conjunction with a pool of faces of the same sex, age and ancestry. All faces in the pool and the CFR/A are standardized to a similar standpoint, quality and with neutral face expression.

Volunteers and then asked to choose the face which they consider to be most like the CFR/A. The face pool assessment is carried out by volunteers who are unfamiliar with all the faces involved, and this is different to the identification of familiar faces by friends or relatives in a real forensic situation.

Gatliff and Snow (1979) used a face pool technique to evaluate the accuracy of their work in craniofacial approximation, and the result revealed an average of 32.5% above the level of chance recognition. However recognition was 26% above chance in another study by Van-Rensburg (1993), 34% above chance in a study by Wilkinson and Whittaker (2002) and 51% above chance in a study by Wilkinson *et al*. (2006). Stephan and Henneberg (2001), utilized four different methods and produced an average rate of 19% above chance. Different factors should be taken in consideration when assessing these results. These researchers followed different methodologies, and the experience and training of the experts may have been significant, so that the more experienced researchers may be more successful (Wilkinson had 5 years' experience while Van Rensburg and Stephan had no previous CFR/A experience and Gatliff had approximately 3 years' experience at that time). A psychology study highlights the difficulty of matching a face to a face pool; Bruce *et al.* (1999) used two images of a target with a neutral expression, one as a high resolution photograph and one as a still from video footage. The video still was incorporated into a pool of similar facial images of other White European young men. Despite the images of the target being selected on the same day, 30% of people could not identify the target from the face pool (Bruce *et al.,* 1999). This suggests that unfamiliar face recognition is fraught with error. A related earlier study by Bruce *et al.* (1991) was performed using a monochromatic surface scan of the face of the target compared to a pool of facial photographs; which recorded a recognition rate of just 26% above chance (Bruce *et al.*, 1991). This suggests that faces without texture and colour (such as CFA/R) are more difficult to match to photographs than real images of faces.

1.6.3 Success Rates

The reliability of CFR/A methods could be assessed using the percentage of positive identifications in forensic circumstances. Where there are many active forensic cases, success rates can alter regularly. It has been suggested that success rates are a biased method of evaluation, as many unsuccessful projects are not considered (Stephan, 2003a). However, since the success rate is calculated from the sum of positive recognitions related to the quantity of active cases undertaken, the number of failed cases must be considered. However, although high success rates indicate the number of positive recognitions in forensic cases, it does not give any indication of the morphological accuracy. It is often also the case that other evidence contributes to a positive identification in forensic investigations, and the morphological accuracy of the reconstruction may not be the most important element in the case (Rynn, 2006).

1.6.4 Morphometric Assessment in CFR/A

Morphometric assessment is the most objective method of measuring morphological accuracy and it utilises biometrics. This is different from all the other methods, which are dependent on subjective recognition/assessment.

Stephan and Arthur (2006) emphasized that for identification purposes it is not crucial to have a CFR/CFA, which is morphologically accurate, as some inaccurate sketches and drawing (e.g. caricatures) are easily recognized (Stephan & Arthur, 2006). Still, by explanation, a caricature is an overstatement of individual features; consequently, a morphologically accurate portrayal of the individual is inevitably the initial point for characterization. Moreover, caricatures usually encompass exaggerate facial appearance and character, which could not be anticipated from the skull without help.

In 2006 also, a blind study by Wilkinson *et al.* (2006) assessed the accuracy and reliability of a 3D virtual CFR method using computed tomography (CT) data of two living subjects from North America; a male and a female. After importing 3D models of the skulls into the computer system, CFRs were created following the Manchester method. For objective assessment between the CFR and the target 3D superimposition of the virtual data of the living face and the CFR was performed: this was carried out using the skull for alignment. Then the surfaces of both faces were compared (Wilkinson *et al.*, 2006) and error colour maps were employed. The results showed that 67% of the CFR surface had less than 2 mm of error, in this study the most reliable reconstructed features were the forehead, eyes, nose, jaw line, and chin, whilst the mouth and ears were the least reliable features. Nevertheless, the researchers suggested further investigation using a laser scan to counteract the effects of gravity caused by patient position, which can affect the facial morphology (Wilkinson *et al*., 2006).

A further project by Quatrehomme *et al.* (2007) assessed the accuracy of CFRs; 25 craniofacial reconstructions were produced by three groups (A-C). Group A was described as "naïve", and did not follow any specific instructions. Group B, applied a detailed anthropological analyses and took advantage of the soft tissue depths of medium nutritional status published in the previous literature in particularly by Rhine and Moore (Rhine & Moore, 2001). Finally Group C followed a comprehensive methodology. The researchers used three strategies, firstly the complexity that increased from group A to group C. Secondly, the results of CFR improved from group A to group B (the performance rising from zero to 27%). thirdly, the performance increased from group B to group C (from 27 to 75%). These results showed a positive correlation between the accuracy of the outcome CFRs and the degree of training and the methodology followed. The researchers showed that the quality of 2D CFR is lower than 3D (Quatrehomme *et al*., 2007).

A recent study by Short *et al*. (2014) evaluated the accuracy of a computer modelled CFR technique using pre-surgical cone beam computed tomography (CBCT) data of 10 living subjects, 5 males and 5 females, aged 18-40 years (*M* = 23 years) with mild skeletal discrepancies: six had a skeletal class III pattern, and four had a skeletal class II pattern. Short *et al.* (2014) comparing the variances between 24 soft-tissue landmarks, 23 linear and 8 angular measurements and a surface mesh carried out on the actual face and the related CFR using 3D software. The overall results revealed that there were no statistical differences for 18 linear and 7 angular measurements between the CFRs and the targets ($p < 0.05$). However, Short *et al.* (2014) admitted that some of these measurements were either underestimated, or overestimated in the CFRs with the nose and mouth "*consistently larger*" in the CFRs than the target. Furthermore, Short *et al.* (2014) stressed the importance of using procrustes superimposition, which might enhance the accuracy level, as their research revealed problems with soft tissue depth and anatomical landmarks' position (Short *et al.*, 2014). Short *et al.* (2014) claimed that their results were equivalent to previous studies (Wilkinson *et al.*, 2006; Lee *et al.*, 2012), as the shell deviation maps revealed that the accuracy level was 56- 90% with areas around the nose, cheek and zygoma showing error level greater than ±2.5 mm. Moreover, the CFR accuracy differed between class II and class III skeletal patterns with the maximum variance seen at the naso-labial angle and the morphology of the anterior nasal spine, suggesting additional research to better characterise the naso-labial soft tissue morphology from skull and dental characteristics is necessary.

1.6.5 Accuracy of CFR/A in Different Ethnic Groups

Most of CFR/A accuracy studies have focused on White European faces, but there are some studies where different ethnic groups were assessed.

A very interesting study in the U.S where the CFA led to positive identification of number of victims in case known as "*Green River serial murder victims*" (Haglund & Reay, 1991). This case dated back to 1982, where the remains of at least 41 victims of the "*Green River Serial Murderer*" have been recovered. Nine different artists were employed to rebuild the facial of features of 24 victims. In this process different techniques of facial approximation were used and compared. As a result, only nine victims were recognised. Haglund and Reay stated that "*Interpretations of the same victim varied greatly… resemblance of the facial approximation to the deceased showed considerable variation, but in some cases was quite accurate. This experience created a unique opportunity to compare different methods of facial approximation techniques and artists, and to comment on their efficacy in aiding identification*" (Haglund & Reay, 1991).

A more recent study, in 2012, Lee *et al.* published a single-blind accuracy research for CFRs using Korean subjects. In this study, three living Korean volunteers (subjects A, B, and C) with no previous orthodontic treatment nor facial plastic surgery or facial deformities were utilized. 3D CBCT images of the skulls and head surfaces plus frontal, three-quarter, and profile photographs of the volunteers were taken. Lee, who had no further information about the volunteer except their ethnic group, used a 3D modelling system (FreeForm Modelling Plus_ software) to produce CFRs. The results reported the three CFRs surfaces had less than 2.5 mm of error comparing to the applicable target face. This study revealed good levels of accuracy and established that the CFR guidelines are also valid for adult Korean faces. Nevertheless, Lee suggested a further study of soft tissue depths in Korean people and north-eastern Asians to raise the accuracy of CFRs (Lee *et al*., 2012).

A study by Fernandes *et al.* (2013) assessed the accuracy of CFRs carried out on Brazilian subject. The authors stated that there were only two databases of soft tissue thickness published for the Brazilian population: one obtained from measurements taken from fresh cadavers, while the other from Magnetic Resonance (MRI) measurements (Fernandes *et al.*, 2013). In that project, the researchers also focused on the significance of "*the presence or absence of hair*" on CFRs accuracy. Consequently, three digital CFRs were produced without different facial hair features: head hair, eyelashes, and eyebrows on a female Brazilian subject. Two CFRs were based on Brazilian soft-tissue thickness and one based on international measurements based on Rhine and Moore database (Rhine & Moore, 2001), the authors clearly stated that "*the facial features (eyes, mouth, nose and ears) were the same for all three reconstructions*" (Rhine & Moore, 2001), which means that the only difference between the three CFR is the soft tissue thickness. Evaluation of the three CFRs accuracy was carried out using a face pool method, where the target face pooled with other 9 faces, all were white Brazilian females and of the same age group (33-47 years), and a total of 22 evaluators took part in the recognition process. Fernandes *et al.*(2013) stated that all the assessor were familiar with the all the 10 individuals who make up the face pool. The target subject was accurately acknowledged by 41% of the examiners in the International Pattern, and by 32% in the Brazilian MRI Pattern, and by the same percentage (32%) in the Brazilian Fresh Cadavers Pattern. The facial reconstructions without hair were correctly recognized, moreover, the results were higher than the results obtained using CFRs with hair, in earlier study (Fernandes *et al*., 2012) from the same skull, where the target face was recognized by 27% of the assessors for the Brazilian MRI reconstruction and around 23% for the Brazilian Fresh Cadaver reconstruction, whilst the CFRs based on international patterns exhibited a lower percentage of 20% (Fernandes *et al.*, 2012).

Fernandes *et al.* suggest that

"*This fact could indicate that hair is not fundamental – and it could even render difficult the recognition, at least when there is no available information concerning the hair characteristics (when no hair is recovered with the skeletal remains)"* (Fernandes *et al.*, 2013). However, in Fernandes *et al.* (2012 & 2013) other facial features were the same, and the importance of these features on the CFRs accuracy were not assessed.

In summary, a number of CFR/A methods have developed and are currently in forensic use. Accuracy studies suggest that there are a number of areas which require improvement and further standards relating to the mouth and lips would benefit this field and lead to more accurate and reliable methods. Therefore this research aims to enhance current methods, by providing reliable standards for the prediction of lip shape from dental pattern.

1.7 Previous Studies on Naso-Labial Soft Tissue Morphology and Dental Pattern

1.7.1 Lips Shape and Dental Pattern

Previous research on dental patterns, facial features and soft tissues had provided overwhelming insights on the strong relationship between facial features and dental patterns (Gerasimov, 1971; Angel, 1978). There is a relationship between the lip shape of an individual and the dental pattern of the same individual (Gerasimov, 1971; Wilkinson, 2004). Stephan (2003a) stressed that the perfect morphological estimation of the majority of the facial muscles is impractical, as a result of the subtle form and great variability of the muscles of facial expression (Stephan, 2003a). Many of these muscles insert at the orbicularis oris sphincter of the mouth, and Stephan specified that it was challenging to grasp how this sphincter's morphology could be anticipated, due to the absence of definable bony attachment marks related to it (Stephan, 2003a). On the other hand, the origin of the muscles which insert into orbicularis oris, such as the zygomatics, was alleged by Gerasimov (1955) to be determined based upon the skull form; for example, on more dolichocephalic (slimmer) faces, the origin of major zygomatic muscles are from the lateral surface of the zygomatic bone, and on more brachycephalic (broader) faces, they initiate from the frontal surface. Furthermore, the depth of orbicularis oris is dependent on tissue depth data, but its morphology is determined by the dental occlusion (Gerasimov, 1955; Gerasimov, 1971).

Some morphological traits relating to lips can be determined from the dental pattern (Wilkinson, 2004; Wilkinson *et al.*, 2003; Stephan, 2003b). By applying a Manchester method for forensic facial reconstruction, experts claimed that a wide dental pattern results into wide lip shape. Protruding maxillary canines suggest a wide, square upper lip shape, with a large section of maxillary teeth exposed when the mouth is at rest (Wilkinson, 2004). On the other hand, the upper enamel line is responsible for suggesting the upper lip shape. Upper enamel line term means the shape of cemento-enamal junction (CEJ) of the maxillary incisor, which is a preferable term in dentistry. When the upper enamel highest points are on the central incisor, the upper lip will take a cupid bow shape. In contrast when the upper enamel line is in a flat position, it suggests that the upper lip line will be in a horizontal line with a cupid bow that is only slightly depressed. Finally, "an individual with prominent mandibular canines suggests that a central depression will be present in the lower and lateral lip fullness. In this case, the shape of the lower lip will follow the enamel line of the lower teeth" (Wilkinson, 2004).

There is a correlation between the maxillary enamel height and upper lip thickness, and also mandibular enamel height and lower lip thickness, which can be used together with sets or regression formula for reconstructing facial features of the individual (Wilkinson *et al.*, 2003).

1.7.2 Soft Nose and Dental Pattern

A research study by Sharma and Nehra (2009) demonstrated a significant correlation between the soft nose and the vertical maxillary skeletal. The study, which was conducted from a sample of 190 adults of both sexes, provided vital information on real nature of dental patterns. This study showed that there was a strong correlation between nasal length and upper anterior facial height. Sharma and Nehra (2009) established that nasal length had a significant correlation with inclination of palatal plane. It is however imperative to note that there was a negative correlation between upward nasal tip inclination and inclination of the palatal plane. Nevertheless, this negative correlation between inclination of palatal plane and upward nasal tip inclination does not outweigh the strong relationship between soft tissue nasal and maxillary skeletal (Sharma & Nehra, 2009).

A study by Meintjes *et al.* (2002) suggested that the nasolabial angle may not reflect a midface vertical discrepancy by itself. The research study depicted that the upturn of the nose with a short nasal length may indicate a change in inclination of palatal plane. Based on this analysis, it is explicit that there exists a strong relationship between skeletal pattern and morphology of soft tissue. This is key aspect in the prediction of mid-face feature by analysing dental pattern (Meintjes *et al.*, 2002).

Rynn *et al.* (2010) produced standards for the prediction of nasal morphology from the skull. In this study, the nasal aperture was described in lateral view as "*echoed or mirrored in the morphology of the nose*". A key landmark in that study was the anterior nasal spine (ANS) since its form indicates the form of the nasal tip. Rynn et al. (2010) claimed that the guidelines of their study were "*sufficiently accurate*" to assist the facial reconstruction and the subsequent recognition.

1.8 Prediction of Mouth Shape from the Skull

General rules for the reconstruction of the mouth and lips have been developed over the years based on the results of several research and studies. Table (1-1) summaries some of these methods, which currently used to predict the mouth and lips from the skull and dental pattern.

Reference /study	Phenotypic Feature	Correlated with	Notes
Broadbent & Mathews (1957)**	Corner of the mouth	Medial border of the iris (interlimbus) distance	Although Stephan (2003b) claimed the method is highly inaccurate. Wilkinson *et al.* (2003) found interlimbus distance is the most accurate method
Gerasimov (1971)**	Thickness (prognathism) of the lips	Prognacy of the teeth, incisors, and mandibular and maxillary alveolar process	These standards change with age, and differs among the same racial group
Angel (1978)**	Line of the lower edge of the lower lip	Just above the middle of the incisor crown	Stewart (1983) demonstrated these standards in the study of terry collection of the skulls and death masks
	Corners of the mouth	The first premolar canine junction	Wilkinson *et al.* (2003) found that this method is the most accurate method.
	Up or down placement of the commissures	Skeletal marking of levator and depressor anguli oris muscles	Angel claimed that there was strong relations
	Lip thickness (prognathism)	The projection of the teeth	Lips thickness also correlated with racial group, the strength of incisive and buccinators muscles
	Nasolabial fold	Skeletal marking of the levator labii superiois & zygomaticus muscles	Strong correlation, and there is possibility of a second lateral crease

Reference /study	Phenotypic Feature	Correlated with	Notes
Gatliff and Snow (1979); Krogman and İşcan (1986)**	Corners of the mouth	Distance between the centre of the pupils (inter-pupillary distance)	Method is highly inaccurate (Latta *et al*., 1991; Wilkinson *et al.*, 2003;Stephan, 2003b)
Fedosyutkin & Nainys (1993)**	Naso-labial fold	Depth of canine fossa	The fold extends from upper edge nostril toward the upper first molar
Ferrario *et al*. (2000)**	Mouth slit or oral fissure	Lower third of maxillary central incisors	Agreed with the majority of sources (Gerasimov, 1975; George,1993; Greyling & Meiring, 1993)
Nehra and Sharma (2009)	Inclination of palatal plane	Nasal length	Negative correlation between upward nasal tip inclination and inclination of the palatal plane
Liliequist and Lundberg (1971)	Soft tissue morphology	Dental maturity, sex, age and racial group	Significant influence of sex and racial group on facial morphology based on the differences on chronological ages
Stephan (2003b)	Mouth width	Canine width plus 57% of the cumulative distance between the lateral canine borders and the pupil centres on each side. Then introduced 75% inter-canine width rule.	The study claimed that these guidelines gave the actual mouth width

Reference /study	**Phenotypic Feature**	**Correlated with**	**Notes**
Wilkinson (2003)	Mouth width	Interlimbus distance and on a radiating line from first premolar-canine junction	More reliable indicator of mouth width than interpupillary distance
	Maxillary enamel height	Upper lip thickness (upper vermillion height)	These standards differ between ethnic group and can be calculated using certain formulae
	Mandibular enamel height	Lower lip thickness (lower vermillion height)	

** These studies quoted from (Wilkinson, 2004).

Table 1-1: *Summary of some of several methods used for determining mouth and lips shapes from the skull, and dental pattern.*

However, some techniques for the prediction of soft tissues from the skull, have not been scientifically evaluated. A study by Stephan (2003b) tested several methods used for determining mouth width from the skull by assessing photographs of subjects of Australian European and Central/South East Asian origin. All participants were photographed in two views: frontal and profile views, with both smiling and neutral expressions, in which these photographs used to assess three popular guidelines used in mouth width prediction. The methods, which being tested in Stephan's study were: A) mouth width as equal to the distance between the pupils (interpupillary distance), B) mouth width as equal to the distance between the medial borders of the iris (interlimbus distance), and C) mouth width as equal to the distance between the most lateral junctions of the canines and the first premolars (Figure 1-1).

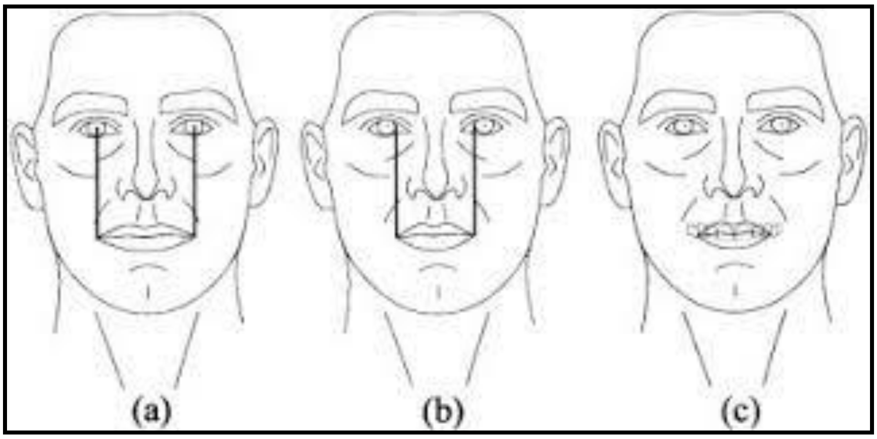

***Figure 1-1:** Traditional methods tested in Stephan (2003b). (a) mouth width as equal to the distance between the pupils (interpupillary distance), (b) mouth width as equal to the distance between the medial borders of the iris (interlimbus distance), and (c) mouth width as equal to the distance between the most lateral junctions of the canines and the first premolars.*

Source: Stephan (2003b), Note: The quality of the figure from the source.

The overall results of that study indicated that those methods are highly inaccurate, with method (B) as accurate for some ethnic groups. In details, Stephan (2003b) suggested that guideline (A) is inaccurate as there was "*highly statistically significant difference*" between the two measurements: mouth width and interpupillary distance with $P < 0.001$. And actual mouth width in the tested sample was 17% smaller than the interpupillary. This suggest that guideline (A) overestimated the mouth width by 11±4mm. For guideline (B), the results suggest that this guideline worked for Asians only, but generally the interlimbus distance was unreliable guideline when applied to all examined sample size, and guideline (B) underestimated the width of the mouth by 2±4mm. The results for guideline (C) indicated that guideline (C) was 25% smaller than the actual mouth width, so similar to (B), guideline (C) underestimated the mouth width by 13±3mm. As the result of these analyses, Stephan in this study introduced a new guideline to predict the mouth width. this new guideline, describing mouth width as canine width plus 57% of the cumulative distance between the lateral canine borders and the pupil centres on each side (Figure 1-2), and Stephan claimed that this guideline predict or "approximate" the accurate mouth width ± 3mm (Stephan, 2003b). In later studies (Stephan & Henneberg, 2003; Stephan & Murphy, 2008) these researchers introduced and defended the accuracy of another guideline known as the 75% rule. Stephan and Henneberg (2003) explained that although the "*inter-canine width plus 57% of the cumulative distance between the lateral aspect of the canines and the pupil centers*" can approximate mouth width, this guideline is impractical since it depends on precise positioning of the pupils "*for which no systematic empirical evidence appears to exist at this stage*". For that reason, a new guideline that was reliant only on hard tissue landmarks (75% inter-canine width) was devised to predict the mouth width. Stephan and Henneberg (2003) claimed that the results showed that the "75% rule" calculates mouth width as accurately as the more complex 57% guideline recommended by Stephan (2003b) (Figure 1-2).

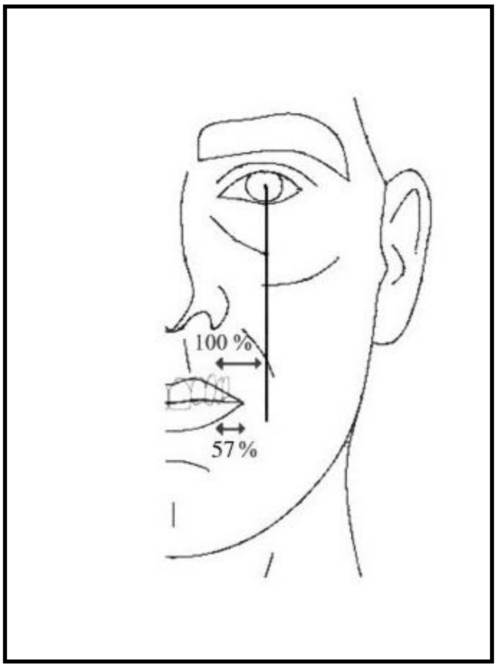

***Figure 1-2**: The new guideline of mouth-width prediction introduced by Stephan (2003b), who stated that: "Assuming symmetry, cheilion falls at a point 57% of the way along the horizontal distance between the canine/first premolar junction and the pupil centre. One hundred percent represents horizontal distance from the canine/first premolar junction to the pupil centre".*

Source: (Stephan, 2003b).

Another study by Wilkinson *et al*. (2003) tested some of the methods used for mouth width prediction. The methods tested included (A) mouth width as equal to interpupillary distance, which is the distance between the centres of pupils and (B) mouth width as equal to interlimbus distance, which is the distance between the medial borders of the iris. The sample was made of 191voulnteers from (84%) White Europeans and (16%) Asians from the Indian subcontinent: 88 males and 103 females, aged 20-60 years. The assessment was carried out using two methods: A) measuring the mouth width and interpupillary and interlimbus distances of 96 subjects directly using Mitutoyo digital calipers and neutral facial expression, and B) by carrying out proportional measurements of the same distances in digital photographs of the same subjects in two photographic views: one view with relaxed expression and the second view showing the teeth of the subjects. The study found that the interlimbus distance is the most reliable indicator of mouth width. As for sexual dimorphism the results revealed that females had significantly smaller measurements in all measured distances: mouth width, interlimbus, and interpupillary distances than the males. Despite this fact, the associations between the interlimbus and interpupillary distances and the mouth width were not significantly different between males and females. Moreover, there were no differences in these associations related to ethnic group. The second aim of the study was to relate the “lip thickness”, i.e. the vermillion border height, with the teeth enamel height. Teeth height term used in Wilkinson *et al.* (2003) study refers to tooth anatomic crown from cemento-enamel junction (CEJ) to occlusal surface, which is the preferable term used in dentistry. The relationship assessed by measuring (1) the maximum upper teeth height, (2) lower teeth height, (3) upper lip vermillion height, and (4) lower lip vermillion height. The measurements number (1) and (2) carried out on photographs of individuals showing their teeth, while number (3) and (4) on 95 subjects using Mitutoyo digital calipers, with the subject displaying a neutral facial expression (Figure 1-3).

Figure 1-3: *Measurements carried out in Wilkinson et al. (2003) to correlate lip height and tooth (crown) height.*

Source: Scottish Data/ Dundee Dental Hospital.

The researcher calculated the correlation coefficients between the upper and lower teeth height and upper and lower lip thickness using Pearson's correlation tests, to establish any relationship between teeth height could be used to expect lip thickness. The outcome suggested that the lips thickness was related positively ($P < 0.01$) to the height of the teeth, which can be used together with sets or regression formula for reconstructing facial features of the individual. Wilkinson *et al*. (2003) stated that *"For White Europeans, lip thickness can be calculated from teeth height by the following Formulae:*

- *Upper lip thickness = 0.4 + 0.6 x(upper teeth height)*
- *Lower lip thickness = 5.5 + 0.4 x(lower teeth height)*
- *Total lip thickness = 3.3 + 0.7 x(total teeth height)*

For Asians from the Indian subcontinent, lip thickness can be calculated from teeth height by the following formulae:

- *Upper lip thickness = 3.4 + 0.4 x(upper teeth height)*
- *Lower lip thickness = 6 + 0.5 x(lower teeth height)*
- *Total lip thickness = 7.2 + 0.6 x (total teeth height)*” (Wilkinson *et al*., 2003).

Obviously each formula of these formulae for a regression line, which mathematically wrote as (Y' = bX + A) where (Y)' is the predicted score, (b) is the slope of the line, and A is the Y intercept (Cleophas, 2009), and this could explained the number in previous formulae. Moreover there are no sex differences in these relationships. However, the results showed that there were ethnic group differences; as subjects with White Europeans had thinner lips than subjects with Indian subcontinent origins (Wilkinson *et al*., 2003).

Wilkinson (2004) summarised the standards (see Table 1-2) taken from previous research results and regularly employed for the Manchester method for prediction of the mouth and lips using dental assessments (Wilkinson, 2004).

Phenotypic Feature		**Correlated with**
Philtrum width		Mid-points of the maxillary central incisors
Mouth width/ corners of the mouth		Radiating lines from the junction between the canine and the first premolar
Commissures shapes		Strength of skeletal markings for the levator and depressor anguli oris muscles
Lips protrusion		Teeth occlusion and anterior teeth inclination
Lips shape	Square upper lip & incompetent	Prominent maxillary canine
	Central depression to the lower lip and lateral lip fullness	Prominent mandibular canines

Phenotypic Feature	Correlated with
Nasolabial fold	Upper edge of nostril to upper first molar Canine fossa depth determines presence or absence

Table 1-2: *Mouth and lips guidelines following Manchester method*

(Wilkinson, 2004).

Several lip models have been developed over time, based on the end-point to mouth slant, lips have been classified into three types, namely: a) Upward, b) Flat, and c) Downward. Further, the thickness or fullness of the lips is also classified into three types, namely: a) heavy upper lip, b) heavy lower lip, and c) equal lips (Wilson *et al.*, 2012).

Angular and linear dimensions of different facial traits/ features in lateral view using cephalograms have been used in various studies to document lip vermillion qualitative evaluations. Some of the most cited studies in this area are those of Neger (1959), Holdaway (1983), Lundstrom *et al.* (1992), Verdonck *et al.* (1993), and Bergman (1999). Conversely, while these studies accounted for both hard and soft tissues, they failed to classify borders and commissures of lips. As a result, other studies such as Ricketts (1968), Farkas *et al.* (1984), and Fernandez-Riviero *et al*. (2003) incorporated the use of photographs to identify the lip vermillion shape. The Likert scale has also been used by several researchers to identify malformed lip shapes, especially in the case of cleft lips (Trotman *et al.*, 2003).

Farkas *et al.* (1984) obtained the standard values for the lip vermillion height (Farkas *et al.*, 1984), but these values are not universally used and most clinicians define the vermillion height subjectively or employ the Likert scale (Astley & Clarren, 2000).

Nevertheless, all of these studies rely mainly on angular/ linear measurements and hence, several morphological attributes such as pouts, flatness and flaps of the lips were not taken into consideration. While complete human profiles can be approximately analysed using the

Fourier series (Ferrario *et al.*, 1995), the detection of finer morphologic characteristics by evaluating the overall lip vermillion have not been conducted, although they are vital for orthodontic diagnoses (Tanikawa *et al.*, 2009).

Despite the numerous studies on facial growth and dental pattern, demonstrating a relationship between dental pattern and naso-labial morphology (Mamandras, 1984; Krogman & İşcan, 1986; Bergman, 1999; Rynn *et al*., 2010), the exact relationship has not been established. Research has shown that skeletal pattern in antero-posterior and vertical dimensions along with the upper and lower incisor inclinations can help in prediction of the morphology of soft tissue and profile (Mamandras, 1984). These inferences have, however, remained controversial and further research on the topic is necessary. There are other theories suggesting that the soft tissue morphology of the face varies with chronological and developmental age, racial group and sex (Wilkinson, 2004). These ideas raise debate among medical, dental, anthropology, and forensic researchers (Bergman, 1999; Wilkinson, 2010) and have led to the call for further research to establish significant relationships.

This research project will therefore focus on the lips and their features, the link between the lip shape and dental pattern, and their relevance in forensic facial recognition.

This study aims to use a lip morphology classification system and establish any relationships between vermillion border pattern and dental pattern.

1.9 Lip Shape and Anatomy

1.9.1 Lip Shape

The lip and the dental pattern can provide reliable information about the identity of an individual. Accurate forensic reconstruction of the lip shape can provide a clue to the person's identity and answer many questions relating to forensic facial recognition process (Rai, 2013).

1.9.2 Anatomy of the Oral Region

An understanding of the structural relationships between the soft tissue anatomy of the face and the hard tissue anatomy of the skull is significant for craniofacial identification methods employed in forensic anthropology and forensic dentistry (Rynn *et al*., 2010; Wilkinson, 2004).

The appearance of the lips varies with facial expression; for example crying, laughing, and smiling. Therefore, from the anatomical point of view, the face has to be in neutral expression to assess the lip anatomy. The lips must make gentle contact with the teeth, which should be slightly separated. Jaws, neck, and facial muscles should not be contracted nor stretched, and the face should be positioned using the Frankfort Horizontal Plane which is a line joining the porion and the orbitale (Carey *et al*., 2009).

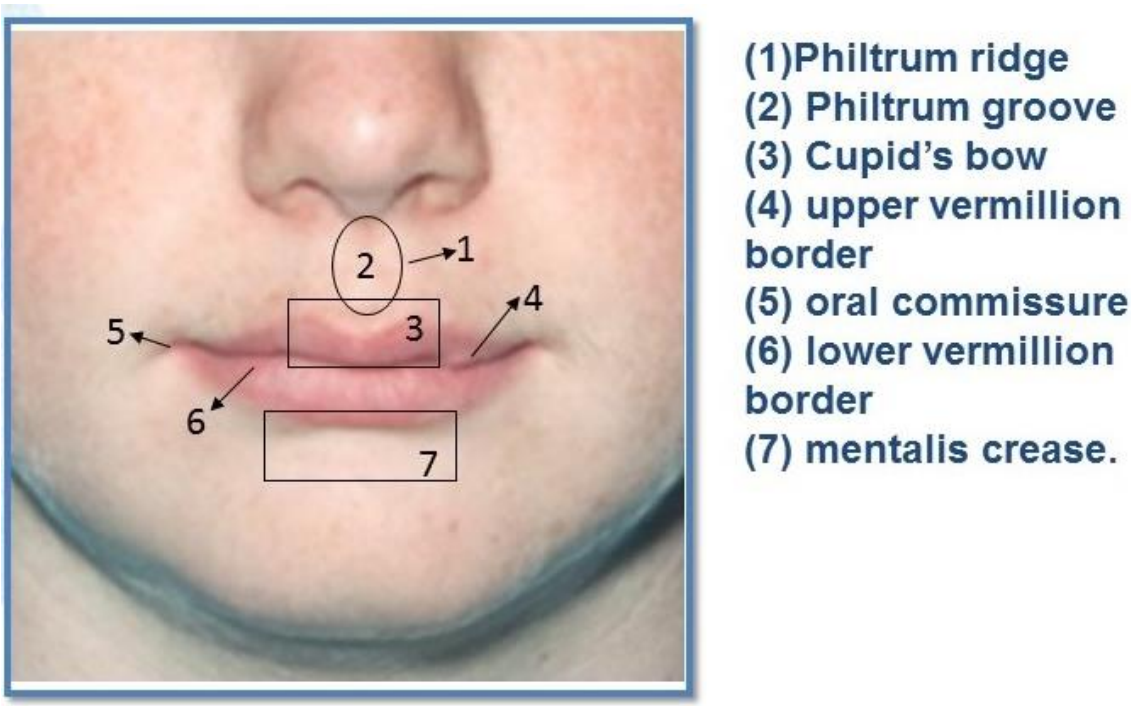

Figure 1-4: *Illustration depicts the major anatomic landmarks of the lips and mouth.*

Source: Scottish Data/ Dundee Dental Hospital.

1.8.2.1 Lips Definition

Lips are defined as the structures that neighbour the oral aperture as shown in Figure (1-4). In the central region, the upper border corresponds to the lower margin of the nasal base. Laterally, the outline follows the alar sulci and both the lower and upper lips meet at the oral commissures. Biologically, the lower limit of the human lips in the region at the centre is the mentolabial sulcus. Structurally, the philtrum and its pillars constitute the upper lip. The lip surface contains four zones, namely: vermillion border, hairy skin, oral mucosa, and vermillion. The normal shape of the lips depends on age, sex, and is influenced by ethnicity (Allanson *et al*., 2009).

1.8.2.2 Vermillion Border Definition

In human anatomy, the lip consists of various parts such as vermillion border, Cupid's bow, and philtral ridge. Vermillion is the red soft part of the lips as shown in Figure 1-4. It is a vital aspect of the lip system and is different from oral mucosa and is made up of a specialized stratified squamous epithelial layer, which is in continuousness with the oral mucosa of the gingivolabial groove. The colour varies from light pink to red depending on many factors such as, the skin colour and the ethnic group. The reason of this red colour might be due to the richness of blood vessels and the thin transparent epithelium overlying these blood vessels. The vermillion is also often termed as ''the lips" (Allanson *et al.*, 2009). The vermillion border is the juncture between the redder tissue (Vermillion) and the lighter skin. It lies between the keratinized hairy skin and the non-keratinized non-hairy mucous membrane (Scheid & Woelfel, 2007).

1.8.2.3 Cupid's bow and Philtrum

The Cupid's bow is the outline of the line shaped by the vermillion border of the upper lip. In an anterior view, this line looks like an archer's bow, which arches superiorly and medially from the commissures up to the paramedian peaks situated at the beginnings of the pillars of the crista philtrae or philtrum with a minor convexity lying between those crests. The philtrum is the vertical channel in the middle line of the upper lip surrounded by these lateral pillars or ridges (Carey *et al.*, 2009).

1.8.2.4 Ageing and cosmetic changes

Ageing causes many changes in the vermillion line; the most significant changes are thinning and the appearance of wrinkles (Hadi & Wilkinson, 2014). Currently, many people undergo various cosmetic and plastic surgery procedures and one of the most popular is lip augmentation for more lip fullness and enhanced pout (Maloney *et al.*, 2012; San Miguel Moragas *et al.*, 2015).

A study by Lévêque and Goubanova (2004) objectively described the age-related changes happening on the lips and perioral skin, in particularly, alterations in dimension of the lips and the appearance of the perioral wrinkles. The study results suggested that the upper lip was more hydrated than the lower lip, and wrinkle number and visibility were directly related to age. Regarded the mouth dimensions, Lévêque and Goubanova (2004) found that the mouth width increased with age, while lip height decreased (Lévêque & Goubanova, 2004).

1.10 Malocclusion Types

The probability of birth deficiencies in the orofacial area is substantial, due to the physical and developmental complexity of the face and the vulnerability to intrinsic and extrinsic influence (Joshi *et al*., 2014). There are two types of malocclusion; skeletal malocclusion and dental malocclusion. Skeletal factors define four important associations (A) relationships of the jaws to each other (maxilla to mandible), (B) jaws to the skull base, (C) maxillary teeth to mandibular teeth and (D) teeth to each jaw.

Skeletal malocclusion is predominantly congenital in that it is produced by the alteration of mandibular and/or maxillary development during foetal growth (Joshi *et al*., 2014). Dental malocclusion is due to the misalignment of the teeth (Angle, 1907). Skeletal and dental occlusion patterns have a substantial effect on the facial profile (Bergman, 1999; Carey *et al.*, 2009). There are three wide-ranging types of skeletal patterns (1) Antero-posterior (class I, II and III), (2) Vertical and (3) Lateral (Miles *et al.*, 2012).

Many popular ways are employed in orthodontics to define the normal occlusion, such as: Angle’s classification (Angle, 1907), Andrews’ six keys of normal occlusion (Andrews, 1972), and the incisor relationship classified by the British Standards Institute (BSI), which will be used to assess the subjects malocclusion types in this study as the main focus in the anterior teeth patterns on naso-labial morphology.

1.10.1 Angle's Classification System

Angle's classification system is considered the simplest and commonest malocclusion classification system for the categorization of occlusal relationships. This system depends on the occlusion relationship between the permanent maxillary and mandibular first molars (Angle, 1907).

Class I neutroclusion generally presents a normal molar and skeletal relationship, on the other hand, class I malocclusion patients have dental problems; for example: crowding, spacing, missing teeth and many other problems (Figure 1-5). The lips and tongue are expected to have "*normal*" morphology and function. In this classification, the maxillary first molar is posterior to the mandibular first molar; specifically, the mesiobuccal cusp of the maxillary first molar is in vertical alignment with the buccal groove of the mandibular first molar. The maxillary permanent canine occludes between the distal side of the mandibular permanent canine and the mesial side of the mandibular first premolar (Angle, 1907).

Figure 1-5: *Class I malocclusion patient, notice: normal facial frontal and profile views, normal maxilla and mandible relationship, molars in Angle class I occlusion; however, the patient has a minor anterior cross-bite; the maxillary lateral incisor is lingual to the opposing mandibular incisor.*

Images Source: Jordanian Data/ Hospital of University of Jordan.

Most papers state that the most frequent malocclusion pattern is Class II or distoclusion (Rynn, 2006). On the other hand, Joshi *et al.* (2014) suggested that class II is the second most frequent after class I (Joshi *et al.*, 2014). In this group, the maxillary first molar is level with, or anterior to, the mandibular first molar; the mesiobuccal cusp of the maxillary first molar is mesial to the buccal groove of the mandibular first molar, the mesial surface of the maxillary canine is mesial to or has no occlusion with the mandibular canine.

Class III or mesioclusion (Figure 1-6) presents with the maxillary first molar more posterior to the mandibular first molar than normal; the buccal groove of the mandibular first molar occludes mesial to the mesiobuccal cusp of the maxillary first molar and/ or mandibular incisors being placed forward to maxillary incisors. The facial profile is characterised by the mandible being prominent relative to the maxilla and is called prognathic.

Class III patients often display a profound skeletal dysplasia, which may promote soft tissue compensatory reactions to retain typical functionality.

Figure 1-6: *Class III malocclusion patient. The patient has facial skeletal disproportions.*

Images Source: Jordanian Data/Jordan University Hospital.

1.10.2 Andrews Six Keys

Andrews examined 120 non-orthodontics patients' dental-casts. All had normal occlusion. Based on these observations he introduced "*The Six Keys to Normal Occlusion*". These keys are : "*Key I – Molar Relationship, Key II – Crown Angulation (tip), Key III – Crown Inclination (torque), Key IV – Rotation, Key V – Tight Contacts, Key VI – Curve of Spee*"

(Andrews, 1972). Generally, any deviation from the normal occlusion is considered a malocclusion. Patients' occlusion types are explained and classified based on three main occlusal milestones: incisor relationship, canine relationship and first molar relationship.

The incisor relationship is best described after assessing and measuring the following parameters: overjet, overbite, centrelines and inter-incisal angles.

Overjet describes the horizontal distance between the incisal edge (tips) of the maxillary central incisors and the labial surfaces of the mandibular central incisors. Measurements done in centric static occlusion are usually expressed in millimetres- normal overjet 2-4mm (Bhatia & Leighton, 1993). Overbite, on the other hand, measures the vertical distance by which the labial surfaces of the mandibular central incisors, in centric occlusion, are overlapped by the maxillary incisors (Figure 1-7).

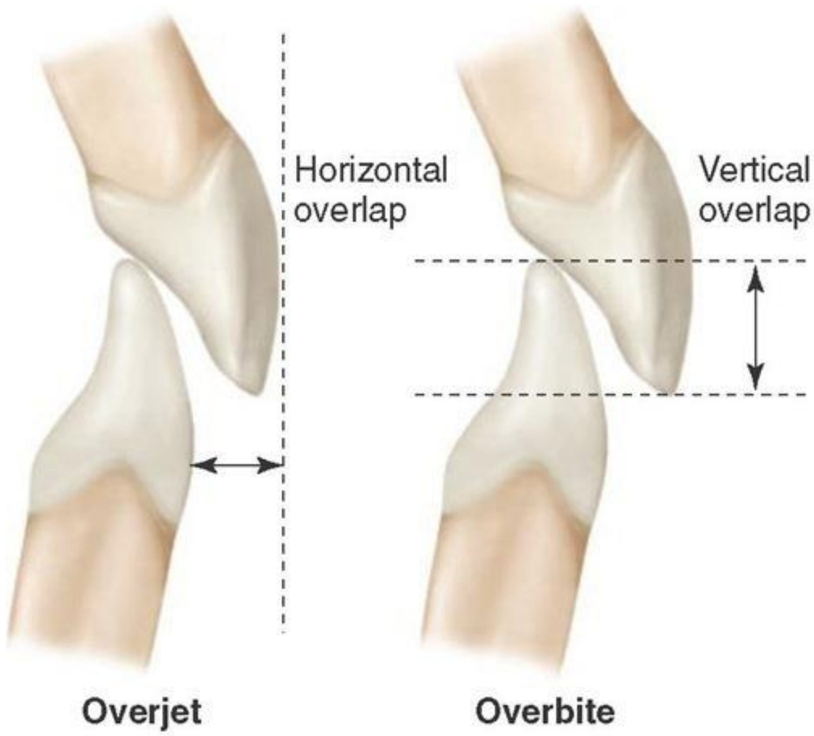

Figure 1-7: *The differences between overjet and overbite.*

Source: The-Crankshaft Publishing (2015).

Standard overbite is when one-third of the mandibular incisor crown height is covered. It is not easy to measure overbite. For that reason, it is typically described by the following terms: reduced, increased, average and anterior open bite (Figure 1-8). Other terms used to describe overbite are complete overbite when the tips of the mandibular incisors bite onto either tooth tissue and/or the palate and incomplete overbite when the mandibular incisors do not make contact with any tissue.

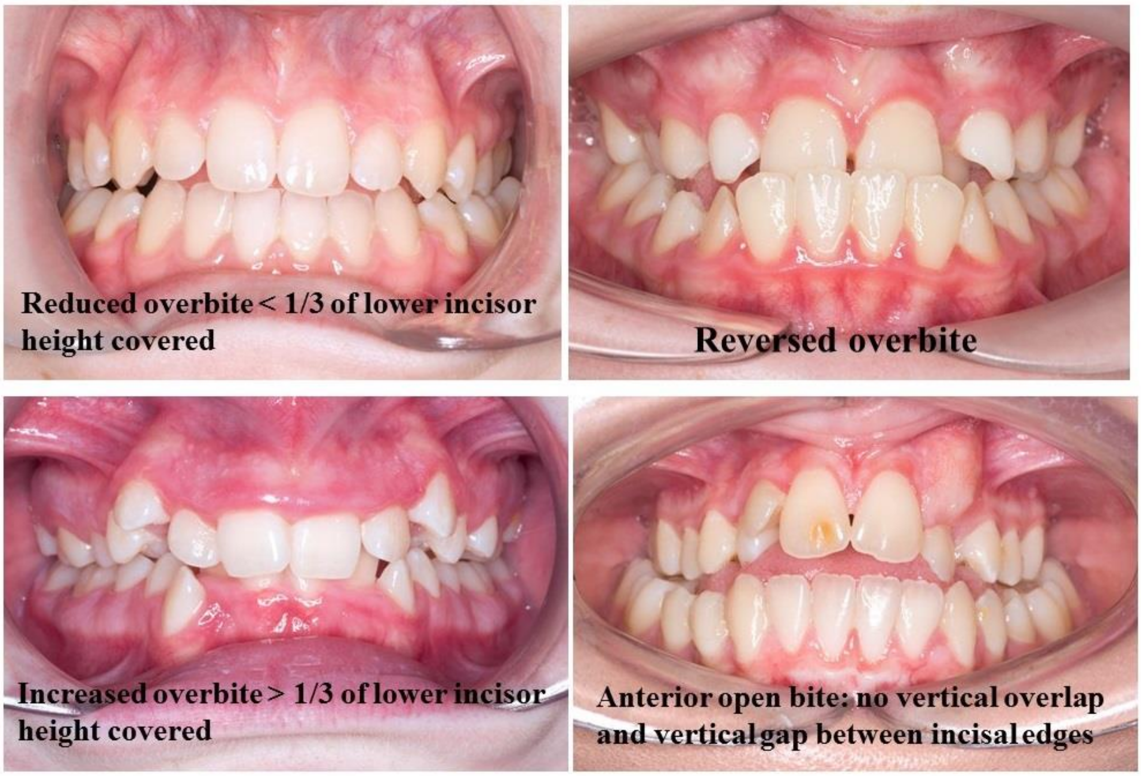

Figure 1-8: *The terms used to describe degree of overbite.*

Source: Jordanian Data/ Jordan University Hospital.

1.10.3 Incisor Relationship

The British Standards Institute classify the incisor relationship, the relation of the upper and lower incisors when in tooth contact (centric occlusion), as Class I, Class II division I or division II, and Class III. The actual angulation of upper and lower incisors relative to the palatal and mandibular planes respectively can only be measured on a lateral skull radiograph (Bergman, 1999). Class I occurs when the lower incisal edges occlude with or lie immediately below the cingulum of the upper incisors.

Class II Division 1 occurs when the lower incisal edge occludes behind the cingulum of the upper central incisors and the upper incisors are proclined in the direction of the lips (Figure 1-9).

Figure 1-9*: Class II div 1 malocclusion patient, notice: due to protrusion of incisors the lips are incompetent in frontal and profile views, no skeletal malocclusion, molars in Angle class II occlusion and the anterior maxillary incisors protrude out towards lips.*

Source: Jordanian Data/ Jordan University Hospital.

Class II Division 2 the lower incisal edge occludes behind the cingulum of the upper central incisors, and the upper incisors are retroclined (the lateral incisors may be proclined). Figure (1-10).

***Figure 1-10**: Class II div 2 malocclusion patient, notice: incisors pulled backward away from the lips. Molars in Angle class II occlusion and the maxillary lateral incisors protrude out towards lips.*

Source: Jordanian Data/ Jordan University Hospital.

In class II, the tongue and facial muscles are forced to adjust through atypical contraction patterns. Characteristically, the mentalis muscle is overactive, uplifting the lower part of orbicularis oris to avoid incompetent lips (Naini, 2010). Finally, class III occurs when the lower incisal edge occludes in front of the cingulum of the upper incisors.

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Chapter 2
Review of Related Studies and Literatures

The methods used in this study are based on previous research, which is summarised in this chapter.

2.1 Relevant Population Variation

Two populations are available for assessment; Scottish and Jordanian. The populations are from a similar ancestry group (Caucasian), although from different ethnic groups, which means they are neither completely different nor identical.

Caucasian is a term devised by German physician Johann Blumenbach in 1795, who classified humans to five groups based on their physical features. These groups were: Caucasian, the white race; Mongolian, the yellow race; Malayan, the brown race; Ethiopian, the black race; and American, the red race (Bernasconi & Blumenbach, 2001). Therefore Caucasian used to describe light-skinned people from Europe, western Asia, and North Africa. Blumenbach incorrectly thought the origin of this group came from the Caucasus Mountains (Andrade *et al.*, 2011).

Caucasians are regarded as having light skin; however, some anthropologists assert that skin colour between Caucasians varies significantly from pale, reddish-white and olive to dark brown. Other characteristics include long and narrow noses, blue eyes and thin lips, and their hair is usually described as wavy or straight (Grolier Incorporated, 2001).

Scientists have determined that there is little association between ethnic groups, used in its general sense, and actual physical disparities in the human race. In the USA for instance, people recognized as European do not share a mutual set of physical features. There is a greater variety of skin colours, hair colours and textures, body sizes, facial structures, and other physical characteristics in this category than in any other human collective identified as a solitary race (Scott & Turner, 1997).

2.1.1 Scottish Facial Features

With regard to Scottish facial features, Sebastiani claimed that people with a Scottish lineage tend to have conservative facial shapes and narrower faces with protrusive, sharply angled nasal bones as their main feature (Sebastiani, 2013). Pavlovich added other features including high and narrow nasal openings, long faces, sharp inferior nasal borders, sloping orbits and large nasal spines (Pavlovic, 2006).

Features of Scottish people vary from light skin and blond hair to dark skin and blue, grey and black eyes. They tend to have curly or straight hair and, even though some Scots have blonde and red hair, they mostly have brunette shades and include every variety and grouping in between (Sebastiani, 2013).

2.1.2 Jordanian Facial Feature

Jordan is made up of a wide variety of people with variances in appearance, but, as most are from Arabic descent, they have been stereotyped with some comparable features; that their skin is commonly darker, their hair is nearly always dark brown or black and their eyes are usually brown (Vanandruel, 1996). These features are relevant to some, but definitely not the majority. However, Arabs generally tend to be homogenous and, as a result, retain similar features of their ancestors, there are many Arabic manuscripts, poems, and ancient paintings dating thousands of years ago, which portray Arabic people with light coloured eyes and even blond hair (Nydell, 2005). This suggests that this is not a new genetic drift but a very ancient one (Fischbach, 2000). So, in short, certain tribes, especially Levant and Arabic Mediterranean countries encompass people with blue eyes and blond or red hair, while others have dark hair with light complexions (Fischbach, 2000). Some groups show a propensity toward long, aquiline faces and dolichocephalic heads, whereas others tend toward round faces and are brachycephalic. Many have almond-shaped eyes and fine features. Their physical variety attests to their long and varied history (Vanandruel, 1996).

2.1.3 Study Population

The subjects studied were taken from the two sample populations: Scottish and Jordanian. The Scottish data was extracted from the Dental Hospital's archive at the University of Dundee; and the Jordanian data came from the archive of the orthodontic department at Jordan University Hospital. The data of the two populations will be combined as one group as we look for consistency within the same malocclusion class. In order to establish a comprehensive relationship between dental pattern and naso-labial morphology, a balanced design of a total of 56 Scottish and 56 Jordanians (Table I-2 and Appendix I) of similar ages and sex ratios in each pair was applied. In each malocclusion class there were 28 subjects that allowed a valid comparison between classes to be made. Finally, each malocclusion class comprised 14 males and 14 females in order to enable the analysis of sexual dimorphism. The same subjects were used for all three methods of analysis: cephalogram, morphological and GMM.

The selected age group was 11-14 years, which is a very sensitive time as growth spurts can occur during these years. Previous studies have suggested that growth starts at about 11 years in females and 13 years in males (Cameron & Bogin, 2012). This rapid growth usually precedes or accompanies puberty, when sex characteristics begin to develop. It is important to notice that these physical developments might occur earlier or later than average in some individuals (Cameron & Bogin, 2012).

The beginning of orthodontic treatment depends on the severity of the case; however, this is generally when a child has lost most of his or her primary teeth, and a majority of his or her permanent teeth have erupted (usually between the ages of 10 and 14) (Badran & Al-khateeb, 2013).

In the CFR field, the only study on British juvenile subjects was carried out by Wilkinson (2002), who measured facial depth using an ultrasonic device on 204 white British children aged 11-18 years with the mean values being divided into two-yearly age group for males and females. Other studies on juvenile subjects were carried out by Manhein et al. (2000) and Utsuno et al. (2010). Manhein et al. (2000) reported results of facial tissue depth measurements on a sample of 551 children and 256 adults of both sexes and different ages and races in the USA using ultrasound technology. Results of that study suggested that age, sex and race are substantial aspects when considering tissue depth means. Utsuno et al. (2010) measured the facial thickness in 339 Japanese children of all skeletal classes, aged 7-18 years using lateral cephalograms. Utsuno et al. had previously (2007) testified facial tissue thickness data for class I Japanese males and females, aged 6-18 years. Utsuno et al.’s study (2007) followed a previous study (Utsuno et al., 2005) of Japanese female children only, which focused on facial soft tissue thickness in all malocclusion classes.

2.2 Prevalence of Malocclusion Types among Relevant Populations

Some studies claimed that malocclusion types are different between different ethnic groups and between populations (Joshi *et al.*, 2014). Eleven ethnic groups are mentioned in that study from a number of studies (Table 2-1), starting with the Angle (1907) study of 1,000 Caucasians, ending with the Phaphe study (2012) of 1,000 urban Indians (Joshi *et al.*, 2014). Two studies were selected: the Angle study (1907), which utilised 1,000 Caucasians revealed that class I is most common in this ethnic group at 69%, followed by class II (Angle, 1907) and the Hamdan study (2001), which will be discussed in the forthcoming section. These two studies examined a relevant ethnic groups to the current research. Other studies were excluded (such as Cohen, 1970) because the study group “white” is very broad class and a term frequently used in USA to refer to whites who are not of Northern European or White Anglo-Saxon Protestant background; whereas, the Scottish sample can be considered white European. The Steigman (1983) study was also excluded as it included other Arabic groups.

Author, year	Ethnicities	Sample size	class I neutrocclusion + class I malocclusion (%)	class II Div 1 + class II Div 2 (%)	Class III (%)
Angle, 1907	**Caucasians**	**1,000**	**I 69.00**	**II/1 19.00** **II/2 4.00**	**3.40**
Altemus, 1959	Black American	3,280	I 83.00	II 12.00	5.00
Cohen, 1970	Blacks	410	I 71.00	II 11.40	6.30
	Whites	349	I 53.60	II 33.60	4.70
Garner, 1985	Black American	447	I/neut 27.00 I/ mal 44.00	II 16.00	8.70
Garner, 1985	Kenyan	471	I/neut 16.80 I/ mal 51.70	II/1 7.90 II/2 0.00	16.80
Phaphe, 2012	Urban Indian	1,000	I 18.00	II 30.10	1.60
Steigman, 1983	Israeli Arab	803	I 85.00	II/1 8.50 II/2 1.70	1.30
Silva, 2001	Latino	507	I/neut 62.90 I/ mal 6.50	II 21.50	9.10
Lew, 1993	Chinese	1,050	I/neut 7.10 I/ mal 58.80	II 21.50	12.60
Garbin, 2010	Brazilian	734	I 55.92	II 42.86	1.22
Hamdan, 2001	**Jordanian**	**320**	**62.50**	**21.50**	**16.00**

Table 2-1: *Prevalence of Class I, II and III Malocclusion in Different Ethnic Groups.*

Note: studies in this table quoted from (Joshi et al., 2014).

Red Bold denote important readings to our study.

There are a number of publications describing dental characteristics associated with the Scottish population, unfortunately, not all relevant to our study. Despite the deficiency of literature in Scottish dental pattern assessment, the Scottish population can be considered as a part of a “larger group”, which is White European, however, most studies are specific for specific countries (Perinetti *et al.*, 2008; Lux *et al.*, 2009, Varrela, 1999), which complicate the comparison.

A study by Khan and Horrocks (1991) assessed a Scots sample of 676 adults above 18 years old undergoing orthodontic treatment to recognize any accompanying trends. In that study factors such as age, sex, source of referral, malocclusion, type of appliance, and interdisciplinary treatment including orthognathic surgery were considered. Results show that the number of orthodontic adult patients is greater than before Khan and Horrocks conducted their study i.e. before 1991. Khan and Horrocks found that the proportion of woman with Class III malocclusions and Class III skeletal bases was greater than found in former studies (Khan & Horrocks, 1991).

Another study by Cedro *et al*. (2010) assessed the number of adults being orthodotically treated in the UK, either within the National Health Service (NHS) or privately, and studied the factors affect their treatment and other details related to orthodontic treatment. The results showed that the majority of treated adults were between 26 and 35 years old, and 72.50% for orthodontic reasons without mentioning the types of malocclusion. Researchers claimed that there were no previous data in the literature with which to compare their results (Cedro *et al.*, 2010).

On the other hand, there are numerous studies on a wide-spectrum of Jordanian dental subjects. Unfortunately, it is very difficult to find explanations regarding Jordanian dental patterns. Some publications describe relationships between teeth and other facial characteristics. Shaweesh *et al.* (2014) investigated the quantitative correlation between the outline shapes of the maxillary dental arch, face, and maxillary central incisor to aid when choosing aesthetic dentures. This study confirmed that the facial outlines could be a reliable detector for artificial anterior tooth selections (Shaweesh *et al.*, 2014), but did not include any data specific to facial morphology. Another study by Al-Dawiri *et al.* (2014) observed the association between Jordanian skin colours and tooth shade under different lighting sources. They found only adequate correlation between skin colour and tooth shade (Al-Dawiri *et al.*, 2014), but did not include any data specific to facial morphology. The results of these two papers are important as they could be employed to predict the facial form and skin colours by careful examination of the maxillary central incisor.

Other publications describe population statistics for dental aspects and eruption patterns. A study by Hattab *et al*. (1996) measured mesiodistal crown diameters using the dental casts of permanent teeth from 198 Jordanians: 112 of the subjects were females and 86 were males, aged 13.4 to 19.1 years. The results show trivial differences between the right and left crown diameters, and males had considerably bigger teeth than females. A comparison of this study with previous studies suggested that Jordanians and Iraqis have similar tooth sizes, but substantially larger teeth than Chinese, Caucasians and Yemenite-Jew populations (Hattab *et al.*, 1996).

There are also some studies describing the prevalence of malocclusions and other oral deformities in Jordanian populations. Hamadan (2001) revealed that 62.5% of 320 participants, age 16 years old, showed class I malocclusion, 21.5% class II, and 16% Class III malocclusion (Hamdan, 2001). An earlier study carried out in 2004 by Abu Alhaija *et al.* examined 1,000 Jordanians from northern regions, ages 13 to 15 years, showed a similar trend where that 18.8% have class II and 1.4% have class III; with teeth crowding detected in 50.4% of the sample (Abu Alhaija *et al*., 2004).

2.3 Cephalogram Analyses

A cephalogram (Figure 2-1) is referred to as a standardised "radiographic view of the jaws and skull permitting measurements. On tracing of these films, anatomic points, planes, and angles are drawn that assist in the evaluation of the patient's facial growth and development." (Mosby's Dental Dictionary, 2008). Therefore, a cephalogram can be defined as radiograph illustration of the craniofacial (image of the configuration of the skull) complex. The technology involves an image or a record that is produced on exposed/processed film by radiography. In other words, it is a head radiograph used especially for orthodontic purposes, as well as for assessing growth changes. It is a two dimensional projection of the lateral aspect of the skull, which is taken in a cephalostat (Bhatia & Leighton, 1993; Ritschel *et al.*, 2013).

There have been a variety of cephalometric analyses used to describe the craniofacial complex and most of them have been dependent on the relatively stable elements in the cranial base, which serve as reference points for measuring growth or changing structures (Bhatia & Leighton, 1993). The process of performing a 'Ceph-analysis' requires tracing the film onto a piece of frosted acetate with a pencil. The aim of Cephalometric analysis is to assess the horizontal and vertical relationships of the major components of cephalograms: the cranium and cranial base, the maxillae, the mandible, the maxillary dentition and its associated alveolar process, and the mandibular dentition and its alveolar process. There are two approaches of cephalometric analysis: metric approach, which use selected linear and angular measures, and employed in this study, and the graphic approach that based on individual's tracing on a template and visual inspection of degree of variation (George, 1987; Ritschel *et al.*, 2013).

Figure 2-1: *Cephalogram, or radiograph of the side of the face.*

Source: Jordanian Data/ Jordan University Hospital.

Cephalometric analysis is frequently used by dentists particularly by orthodontists to study the skeletal relationships in the craniofacial complex. In addition, cephalometric analysis has many other uses, such as (1) predicting future growth changes, (2) studying the success of an ongoing treatment plan as well as (3) evaluating longitudinal growth and dentofacial proportion (Bhatia & Leighton, 1993; Ritschel *et al.*, 2013). By comparing the patient's facial profile radiographs to normal values in order to identify deviations from the expected average, the cephalometric technology allows for a complete morphological analysis and assist in the identification of morphometric features that contribute to malocclusion (Bhatia & Leighton, 1993; Ritschel *et al.,* 2013).

One of the reasons the cephalometric radiographs have been useful in the planning of treatment is due to their ability to facilitate the process of envisaging potential/future facial growth (Ritschel *et al.*, 2013). When identifying a treatment plan, it is important that orthodontists not only focus on the current state of the facial structure, but also determine what may happen in the future (George, 2007). Despite the expected limitations that may be experienced in predicting future changes with a single cephalometric radiograph, longitudinal cephalometric analyses over time can be beneficial in helping to monitor facial growth (Bhatia & Leighton, 1993) and the progress and efficiency of orthodontic interventions (Rai & Kaur, 2013; Ritschel *et al.*, 2013).

2.3.1 Cephalometric Standard Values

The cephalometric standard values offer beneficial guidelines in orthodontic diagnosis and treatment planning (Ritschel *et al.*, 2013). Nevertheless, it is impossible to apply these values to every case, given that these values represent average value of a certain population, which might be unsuitable for individual treatment goals (Hamdan & Rock, 2001). Additionally, it has been recommended to consider the patient’s age and ethnicity for orthodontic analysis (Moyers, 1988).

The following paragraphs will concisely discuss the beginning of some of the currently applied cephalometric standard values of different races.

In 1947, Björk published complete and frequently cited cephalometric values. These value taken from two groups: (1) 322 Swedish boys aged 12 years and (2) 281 army recruits aged 21 years (Björk, 1947).

In 1948, Downs introduced the perception of standard values for cephalometric measurements. Downs defined the balance and harmony by examining 20 individuals have perfect untreated occlusions (Downs, 1948). Downs’ study considered an early analysis proposed standard values based on examining a selected study group, these standard values were demonstrated to be extraordinarily reliable regardless of the methods of their beginning (Hamdan & Rock, 2001).

In 1953, Steiner introduced a simple and easy to use system of cephalometry. Steiner system using SN (Sella to Nasion) plane, or anterior cranial base, presenting a basic reference plane as according to Steiner "*if head deviate from true profile position these two mid line points are minimally moved, even if the head rotates in a cephalostat*." (Steiner, 1953).

In 1956, Ballard published the results of his study on children and adults at the Eastman Dental Hospital, London (Ballard, 1956). The results of Ballard were later known as the Eastman Standard Values, after all values were rounded to the nearest whole numbers (Mills, 1982). MacAllister and Rock (1992), defined the suitability of the "*Eastman Standard Values*" by studying a selected cephalograms where the results of incisor angulations were very close to Ballard's or Eastman values.

In 1957, Riedel investigated girls elected as Princesses during the Seattle Seafair Week. Hamdan and Rock (2001) considered his selection as an extreme example of "*selected sample*". In this contest, the subjects were selected on certain criteria related to their exterior look, character, and self-confidence to characterise their communities. The results of their study revealed that the skeletal patterns of the finalists were alike to recorded normal occlusion in previous studies. The results confirm the opinion that the people perception of facial aesthetics come to an agreement with cephalometric standards reputable by orthodontists based on normal occlusion definition (Riedel, 1957). These results contradict with a later studies by Peck and Peck (1970), who examined 52 facially attractive models, beauty competition finalists, and artistes. From their analysis, research suggested that the general public appreciated a fuller, more protrusive dentofacial pattern rather than what have been considered a normal facial profile in cephalometric standards (Peck & Peck, 1970).

In 1966, Taylor and Hitchcock published the results of their study on 40 Alabama children, aged 8-18. The research selected sixteen of thirty-two measurements previously analysed, the selected 16 standards considered as "*statistically significant and clinically useful*". Statistical results verified that there were no sex dimorphism detected in the facial profile of the examined sample (Taylor & Hitchcock, 1966). Alabama Analysis showed that the values of 6 cephalometric measurements significantly different than the values obtain from previous studies. Therefore, Taylor and Hitchcock introduced the concept of population specific values in Cephalometrics, in this case "*Alabama Analysis*" to the world of orthodontics (Taylor & Hitchcock, 1966).

Another significant published cephalometric parameter study was from the University of Michigan by Riolo (1974), where standards were derived by longitudinal study of children and young adults (Riolo, 1974). Then, in 1975, Broadbent *et al*., published the Bolton Standards, which were derived from analysing group of males and females, who have "*good faces and occlusions*", aged 18 years (Broadbent *et al.*, 1975). Another longitudinal study by Bishara (1981) to create normative cephalometric standards by studying 35 individuals, who have a clinical normal occlusion and no evident of facial disharmony. Studies on subjects with normal occlusion were continued by McNamara (1988) who investigated the records of 125 white males and females, aged over 16 years, and the results of this study referred to as "*Michigan Standards*", which is regarded as the American corresponding standards of the "*Eastman Standards*" (McNamara, 1988). In 1993, Bhatia and Leighton published a manual of facial growth, based on computer analysis cephalometric (Bhatia & Leighton, 1993).
The orthodontic literature contains other publications analysing different ethnic groups for example, Hamdan and Rock (2001) reported on a study comparing Jordanian cephalometric norms to British cephalometric norms using Eastman Standards. So far it was the only published paper concerned with Jordanian norm values. Also recent studies analysing other

Arabs population: Saudi Arabia (Aldrees, 2011), Al-Kuwait (Al-Awwad *et al*., 2014), Morocco (Ousehal *et al.*, 2012), Libya (Rani & Faituri, 2008) have been carried out.

2.3.2 Lips Competency

Competent lips is the term used when the lips contact one another without effort when the mandible is in rest position (Naini, 2010). Since lip competence can be linked to teeth inclination, overjet and overbite, a number of approaches assess lip sealing, for example visual examination clinically, photographs (Figure 2-2), cephalometric radiographs and others. The lips were categorised according to Foster and Day (1974) as: normal, contracting and lip trap. Normal or competent lips are when upper and lower lips make contact in front of the maxillary anterior teeth in a stress-free posture without effort. Contracting lips refers to lips that meet in front of the maxillary anterior teeth with effort. Lip trap describes the case when the lower lip lies entirely or partly behind the maxillary anterior teeth. Patients with incompetent lips show distinct movement of the lower lip and unfamiliar movement of the tongue in an effort to close the lips (Yamaguchi *et al.*, 2000).

Figure 2-2: *Lip competence pattern. (1) Competent lip (2) Contracting lip: notice the circumoral muscles contraction (3) Trapped lower lip behind maxillary incisors.*

Source: Jordan University Hospital and Dundee Dental Hospital.

2.3.3 Use of Cephalometric Analysis in Forensic Science

There are many scientific techniques in the history of forensic science that have been employed for assembling post mortem information. As technology has developed, this has enabled more detailed examination and analysis. Forensic science has been vital, especially in the law enforcement sector where forensics is carried out in connection with civil/criminal law. However, the practice is also used in other areas such as biology, geology and archaeology. The estimation of physical features is a vital tool in the forensic examination, particularly in unidentified, extremely decomposed, fragmentary and mutilated human remains (Holton *et al*., 2012). Regression analysis also shows that the cephalic measurements provide a better prediction of stature (Gil *et al*., 2011). Forensic radiology is a new sub-specialisation that has developed in the field of forensic medicine and cephalometric analysis to increase its effectiveness (Scott & Turner, 1997).

The examination of different variations and craniofacial-relationships with the use of cephalometric analysis amongst ethnic groups has long been a subject of investigation in forensic sciences. In addition, its application in the planning of orthodontic treatment and orthognathic surgeries is also beneficial in evaluating ethnic groups in forensic science. One of the benefits from cephalometric analysis in forensic casework is sex identification of unidentified mutilated bodies. A study had shown that there is a greater reliability of sex determination from skulls from radiographic cephalometry (Scott & Turner, 1997). In forensic odontology, the sum of all the features of the teeth and their related structures forms an exceptional totality and provides the resources for body identification. The radiographs obtained in cephalometric analysis are used in forensic dentistry and in litigation for age estimation (Gil *et al*., 2011; Scott & Turner, 1997). Lastly, the development of the technology has led to the breakthrough of performing analysis on dry skulls that lack soft tissue. Cephalometric analysis has enabled forensic identification through the analysis of the five major components of the head, such as (1) the cranium (2) the cranial base, (3) skeletal maxillae, (4) skeletal mandible and (5) the alveolar process and the mandibular and maxillary dentition (Holton *et al*., 2012). Cephalograms are useful in pathological observation, evaluation of malocclusion, the assessment of orthodontic treatment, and prediction of facial growth. Depending on the purpose of the cephalogram analysis, various anatomical and constructed landmarks can be employed.

In short, the development of cephalometric analysis, it has played a major role in forensic identification, which has been a breakthrough for post mortem and legal investigation.

The use of cephalograms for craniofacial analysis is a well-established orthodontic technique utilising standardised images, measurements and procedures. This method will therefore be employed for this study to analyse the soft tissue morphology related to the dental pattern.

2.4 Photographic Analysis by Morphological Evaluation

In the literature, many scientists suggested links between lips fullness and dental pattern. Gerasimov (1971) used the terms thin lips and thick lips analogously to lip fullness in his study. He stated that small straight teeth indicated thin lips and an orthognathic profile and that thick lips were accompanied by protruding big teeth and a prognathic profile. He also linked the height of the enamel of the central incisor and the vertical height of the vermillion border. Gatliff and Snow (1979) agreed with this approach, as they found the vertical height of the lips could be predicted from the "*gum line-to-gum line*" measurement. Wilkinson *et al*. (2003) also used the terms thick and thin similarly, and they suggested that there is a correlation between maxillary enamel height i.e. upper anterior teeth and upper vermillion height, and also mandibular enamel height i.e. lower anterior teeth and lower vermillion height, which can be used together with sets or regression formulae for white European and

Indian subcontinent populations, which discussed in section 1.7 in this thesis (Wilkinson *et al.*, 2003). In a more recent study, Ritz-Timme *et al*. (2011) assessed lip fullness in three European populations and called it "*labial breadth*". They used three terms to assess lip fullness: narrow, average, and broad, using the DMV atlas that evaluated 43 morphological traits specifically for Germany, Italy and Lithuania (Ritz-Timme *et al*., 2011). Regarding sex dimorphism, previous studies such as Farkas *et al*. (1984) and Ferrario *et al*. (1993) claimed that oral measurements: the mouth width and lip height, were lower in females (Farkas *et al.*, 1984; Ferrario *et al.*, 1993). Even though Medlej (2014), who is a Lebanese calligraphy artist, claimed that men generally have thinner and less fleshy lips than women (Medlej, 2014). Philtrum shape and Cupid's bow shape have been examined in previous studies, such as İşcan and Helmer (1993), who mentioned numerous facial morphological features that could be detected from photographs, including philtrum shape. He used four features to describe philtrum shapes: flat, deep, sides parallel, and sides divergent. Additionally, he described the Cupid's bow as the "*upper lip notch*" (İşcan & Helmer, 1993), which has three shapes: absent, wavy, and V-shape. Another significant study was carried out by Mori *et al.* (2005) on 109 children aged 5 to 6 years. Mori *et al.* classified the philtrum shapes into triangular, parallel, concave, and flat (Mori *et al.,* 2005). Ritz-Timme *et al.* (2011) confined their study to classifying the philtrum sides as either parallel or divergent and the depth of the philtrum as either deep or shallow. Ritz-Timme *et al.* (2011) also used the term "*upper lip notch*" and described it as wavy, narrow, or relatively straight. A recent study by Wilson *et al.* (2012) categorised philtrum shapes into six categories: smooth philtrum, normal gradient, and indentation near columella, indentation in the middle, indentation near the vermillion border, deep groove from columella to the vermillion border, and deep groove extending through the vermillion border. Moreover, they had three categories to describe the width of philtrum:

narrow, average, and wide (Wilson *et al.*, 2012). Cupid's bow shape, in Wilson *et al.* (2012) study, had three categories: flat, U-shaped, and V-shaped.

Ritz-Timme *et al.* (2011) described the commissure as "*orientation of mouth corners*" and had three classes: slightly up, straight, and slightly down. In Wilson *et al.* (2012) the position of the mouth's angles had three categories: upturned, straight, and downturned.

Therefore there are numerous previous studies where lip shape classification has been developed and this research intends to combine and utilise these previous classification systems to facilitate the morphological assessment of lip shape from 2D photographic records.

2.5 Geometric Morphometric Evaluation of Lip Photographs

Another method employed in this study is geometric morphometric (GMM) evaluation of lip photographs. GMM is considered a subfield of statistics, which explore the form based on the analysis of Cartesian landmark coordinates (Bookstein, 1997). The term comes from the Greek words *morphe*, which means shape, and *metron*, which means measurement. Therefore, this discipline concerns numerical analysis of the interaction between size and shape. Moreover, this approach conserves the geometry of the surface landmarks during the statistical analysis to allow the actual form to be preserved (Bookstein, 1997; Dryden, 1998).

GMM is a contemporary method of morphometrics, a speciality with an extensive history and a diversity of procedures. GMM makes widespread use of computer software and digital imaging techniques, which provide the tools to analyse data within a statistical framework (Bookstein, 1997).

Morphometrics is the quantitative statistical description of biological variation in form. Form means shape and size combined. Size is defined as the measurement of the scale of an object. Shape is the geometric information that remains after eradicating changes in size and position

(Pavlinov & Mikeshina, 2003). Therefore, this approach has been termed geometric morphometrics because it maintains the geometry of the landmark configurations during the course of the statistical analysis and as a result the statistical results represent the actual shapes or forms (Mitteroecker & Gunz, 2009).

2.5.1 Landmarks Selection for GMM

Landmarks are defined as distinctive anatomical points that can be similarly recognized in all study specimens (Zelditch *et al.*, 2004). Landmarks that are corresponding are essential to geometric morphometric methods, and because landmarks perform a crucial role, there are defined standards for how they should be located. Zelditch *et al*. (2004) recommend that landmarks (1) should be symmetrical anatomical points that (2) do not vary their typological locations comparative to other landmarks, (3) offer sufficient coverage of the morphology, (4) are repeatedly and reliably present, and (5) could be found on the same level/plane. Zelditch *et al.* recommend that landmarks should be selected depending on the research aims. However, they should also be picked on a comprehensive scale so as not to limit the possible detection of new shape information (Zelditch *et al.*, 2004).

2.5.2 Type I, Type II and Type III Landmarks

Bookstein *et al.* (2004) categorize and grade landmarks depending on the simplicity involved in detecting their positions on biological structures. Landmarks are usually categorized into three types: type I, type II and type III (Meintjes *et al.*, 2002).

Type I landmarks refer to homologous points that have the same comparative position throughout all the samples. These landmarks have a well-defined anatomical position, which is straightforwardly locatable and repeatable by researchers and within samples. Examples of type I landmarks on the skull include an intersection between sutures, such as the bregma, nasion, and intermaxillary sutures, or the location of a small foramina and canal, such as the mental foramen and incisive canal (Hallgrímsson *et al.*, 2007).

Type II landmarks are defined as points the anatomical positions of which stay the same within the same sample geometric evidence rather than having well-defined anatomical loci. Points of greatest curvature along a bony edge, such as the jugale point, for example the point at the zygomatic bone when frontal and temporal processes join together, or the cephalometric landmarks point A in the maxilla and point B in the mandible, or the tips of the ends of bony projections, such as the anterior nasal spine, or the intersection of sutures with edges, such as the frontomalare orbitale along the orbit, would all be classified as type II landmarks (Hallgrímsson *et al.*, 2007).

Type III landmarks are those landmarks that are more challenging to localize and, therefore, these are typically extreme points that make accurate determination of their exact locations across all specimens difficult. Examples of type III landmarks include the ectoconchion, angle of the mandible, and euryon, which is defined as the point with a maximum curvature or the point utmost with respect to a specific structure (Hallgrímsson *et al.*, 2007).

Another type of landmark, which could be used in GMM studies, is the semilandmark. Semilandmarks refer to successions of points alongside an outline in two dimensions, while in three-dimensional studies semilandmarks are those points along curves or planes. These landmarks would be categorized as the most difficult of all landmark types as their precise location on a specimen is hard to define properly (Mitteroecker & Gunz, 2009). The importance of semilandmarks in GMM is that they take account of information about topographies on samples that lie between landmark points (Gunz *et al.*, 2005). Semilandmarks, although deficient in terms of precise anatomical locations, could be exceptionally informative about biological form, which cannot be acquired from other landmark types (Gunz *et al.*, 2005).

Landmarks are ordinarily taken using a diversity of methods with different devices. Annotating two-dimensional photographs on a computer screen (Mitteroecker & Gunz, 2009) commonly acquires two-dimensional landmarks.

In traditional morphometrics, form, which consists of shape and size, is quantitatively studied (Richtsmeier *et al.*, 2003). In GMM applications, the shape of the object is known as the arithmetical information after other factors, such as scale, location and rotation, are omitted. As the size of a sample has influence on the dimensions and consequently affects the results achieved, in some GMM applications, the size factor is removed in order to study the "*pure*" shape (Kendall, 1977). This is the principle behind the Procrustes analysis (Bookstein, 1991). Traditional metric analyses operated in forensic anthropology and human identification commonly do not set shape apart from size as a distinctive variable and this could influence the readings made about morphological variation.

2.6 GMM Techniques

Depending on the aim of the research, landmarks types, and the nature of the analysed specimen, GMM offers several methods and models for analysing landmark coordinates. Examples of these methods are Procrustes superimposition technique, which is the most well-known and acknowledged for its comprehensive mathematical and statistical properties (Bookstein, 1997; Dryden & Mardia, 1998). Other GMM techniques are Euclidian distance matrix analysis (Lele and Richtsmeier 1991), elliptic Fourier analysis (Lestrel, 1982), and many other traditional morphometric approaches such as: Blackith and Reyment (1971), Marcus (1990), and Oxnard (1983). Other techniques applied in certain discipline such as: Baak and Oort (1983) in histology and in stereology (Weibel 1979; Baddeley & Vedel Jensen, 2004). Rohlf (2003) made a thorough statistical evaluation of several of these approaches and techniques.

2.6.1 Generalized Procrustes Analysis (GPA)

The most frequently used method for landmark position analysis is Generalized Procrustes Analysis (GPA), otherwise known as Procrustes superimposition (Viscosi & Cardini, 2011). GPA is theoretically considered to be the most developed approach for GMM landmark-based analyses. Moreover, most morphometricians and biologists often choose GPA as a "default" method (Cardini, 2012; Viscosi & Cardini, 2011; Zelditch et al., 2004). Two of the main strong points of the GPA method are the constancy with the mathematical theory of shape and its advantageous statistical properties (Cardini, 2012). To simplify the steps of GPA, the procedure is summarized in Figure (2-3) (Mitteroecker & Gunz, 2009):

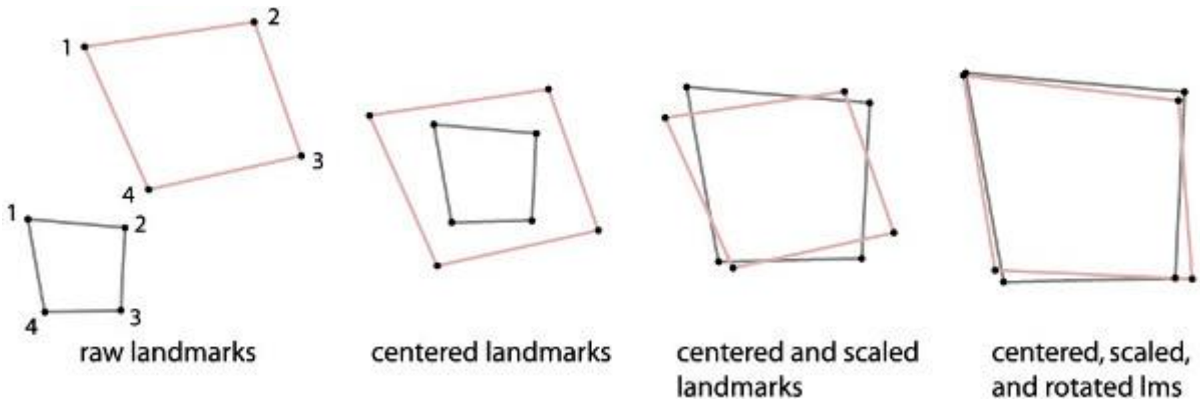


Figure 2-3: *"The three steps of Procrustes superimposition: translation to a common origin, scaling to unit centroid size, and rotation to minimize the sum of squared Euclidean distances among the homologous landmarks. The resulting landmark coordinates are called Procrustes shape coordinates." (Mitteroecker & Gunz, 2009).*

The GPA homogenizes the landmark outlines by using mathematical algorithms and regulates the raw landmark data so that all the specimens in the study are aligned into a common harmonized system. This allows collective and comparative data analysis as the landmark points are placed in a similar alignment and are regulated for size differences. Any information not related to shape is eliminated (Rohlf, 2003). After this, GPA converts the data so that they have a common centre (or centroid) and a common unit centroid size, and the same orientation (O'Higgins & Strand-Viðarsdóttir, 1999; Slice, 2005; Viscosi & Cardini, 2011).

This means that all the raw landmark data are re-distributed around the new average shape, which is centred at the origin (Weber Fred & Bookstein, 2011). The size of each case is assessed by computing the scattering of the landmarks around the centroid and the landmark organizations are scaled to the same unit centroid size, which is achieved by reducing the summation of the squared distances between each landmark and their analogous centroid points (Adams *et al.*, 2004; Cardini, 2012; Slice, 2007). The next step is to rotate the landmark coordinates and, consequently, the Procrustes distances between the specimens are also reduced by minimizing the squared distances between the landmark outlines and the centroid (Adams *et al.*, 2004). The size is detached from the shape data and a distinct size variable is produced. Subsequently, the researcher could either explore shape variables or size independently of each other or, if preferred, use shape and size in conjunction to study the form and allometry.

As a result of superimposition, differences in the landmark coordinate sites reveal differences in the shapes of the samples (Slice, 2007). Landmark coordinates could then be statistically analysed using different methods, such as principal component analysis (PCA), or multivariate statistical analyses, for instance discriminant function and canonical variates analyses, to detect and calculate group differences (Slice, 2007). Procrustes-based geometric morphometric methods have some limitations. The main limitation, which is repeatedly debated in the literature, is the "*Pinocchio effect*" (Cardini, 2012; Viscosi & Cardini, 2011; von Cramon-Taubadel *et al.*, 2007; Zelditch *et al.*, 2004). The Pinocchio effect occurs when one executes GPA on raw data; the locations of the landmarks denote shape differences as a whole but the method cannot necessarily express the extent of the shape variation occurring at individual landmarks between specimens (Viscosi & Cardini, 2011). If significant variation between landmark outlines is partially related to just a single or a few landmarks within the configuration, then the variation between these landmarks may be spread out through all the landmarks used in the study (Cardini, 2012; Viscosi & Cardini, 2011; von Cramon-Taubadel *et al.*, 2007; Zelditch *et al.*, 2004). The least-squares criterion that is used to superimpose landmark configurations may smear the shape displacements of the most variable landmarks through the whole configuration of the landmarked specimens (Zelditch *et al*., 2004). Procrustes superimposition can reduce the disparity in shape between different samples by distributing the variation between landmarks uniformly over the whole configuration. However, this may misleadingly lessen the variation occurring at different landmarks and, perhaps, creates unpredictable estimators of the mean form and shape (Suazo *et al*., 2008). Nevertheless, the literature has revealed that the Procrustes method is more precise when calculating approximately the true mean shape of an alignment of landmarks than other GMM methods (Rohlf, 2003).

2.6.2 Principal Component Analysis (PCA)

Principal Component Analysis (PCA) is a significant statistical tool in GMM analysis for producing shape variables and general shape patterns that are uncorrelated with one another (Polly *et al*., 2013). Scholars suggested that PCA dimensionality is appropriate for any statistical analysis (Rohlf, 1993; Dryden & Mardia, 1998; Zelditch *et al*., 2004) and "*one of the most widely used methods for exploratory multivariate analysis*" (Polly *et al*., 2013, Klingenberg, 2011). In other words, PCA can be used to study the most important structures of shape difference and similarity among objects in a sample (Klingenberg, 2011).

PCA combined with the visualization tools such as graphs in a GMM analysis (Figure 2-4) may provide understanding of the covariation among the shape variables and exploring the associations of shape with other factors. Examples of using PCA, are the work of Bulygina *et al*. (2006), who studied the correlation of adult cranial shape in humans with their new born morphology and Toro-Ibacache *et al.* (2014),who studied the craniofacial skeleton morphologic variations patterns of the cleft palate patients and compare it with unaffected subjects. Note, high correlation does not necessarily mean morphological similarity; the actual head shapes at different stages could be quite different.

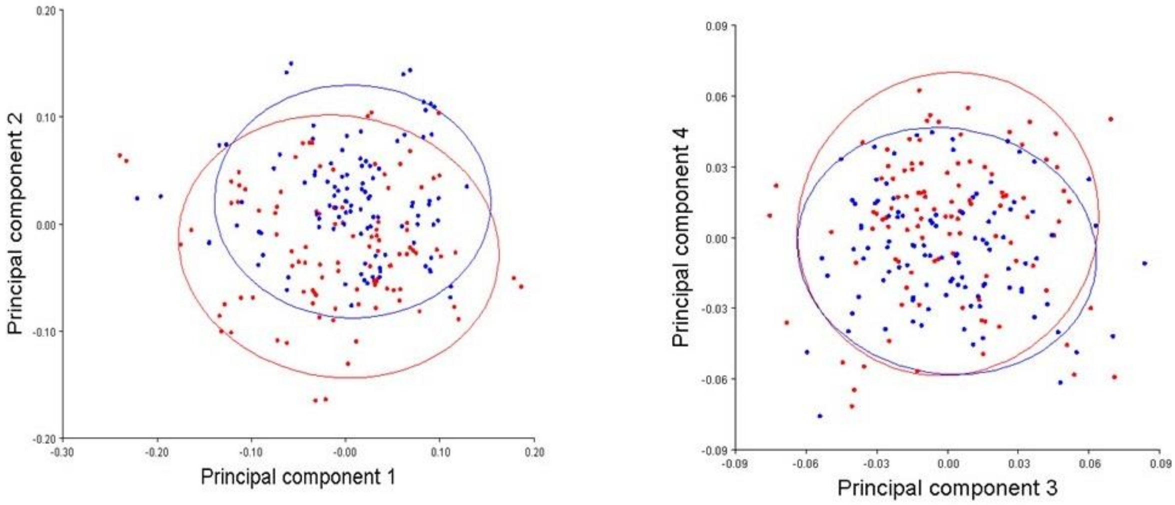


Figure 2-4: *Nearly perfect overlap between the two vermillion borders of studied population on the scatterplots of the first four PCs as an example of PCA use along with the GMM visualizing tool*

In other statistical programmes, PCA frequently is founded on a correlation matrix. For this reason, PCA in software used for GMM analysis, in particularly, MorphoJ, PCA is listed under a covariance matrix (Klingenberg, 2011).

PCA is closely related to methods for computing morphological incorporation by means of the distribution of eigenvalues. Eigenvalues are "*a special set of scalars associated with a linear system of equations (i.e., a matrix equation) that are sometimes also known as characteristic roots, characteristic values (Hoffman & Kunze, 1971), proper values, or latent roots*" (Marcus & Minc, 1988).

The number of PCs to present is determined by using a threshold of 10^{-14} for the eigenvalues, the variance of eigenvalues is a quantity of integration that calculates how much the variation is focused in few space or spread across many foci of shape space (Klingenberg, 2011). If "*there is no integration at all, if there are equal amounts of variation in all directions of shape space, this variance will have its minimum value of 0"* (Pavlicev *et al*., 2009).

2.6.3 Euclidean distance matrix analysis (EDMA)

Another form of landmark-based GMM analysis is Euclidean distance matrix analysis (EDMA). EDMA does not record sets of landmarks and accordingly it does not count on superimposition methods or a common coordinate system (Cole & Richtsmeier, 1998; Lele, 1991; Lele, 1993; Lele & Richtsmeier, 1991; Lele & Richtsmeier, 1992). EDMA uses a form matrix and assesses shape differences between two cases by looking at all of the possible Euclidean linear distances between homologous landmarks. A form matrix is created from the Euclidean distances from each case and the matrices are compared to one another to detect how the linear distances may differ between cases (Ferrario *et al*., 1993). EDMA offers a method for classifying and picking out prominently shaped landmarks based on the linear distances that are the most variable between the cases (Ferrario *et al*., 1993).

EDMA does not depend on a haphazard registration system but the analysis and visualization of the results can be more difficult to carry out (O'Higgins & Jones, 1998). Linear distances between landmark locations do not eliminate the issue of size from the data, which means mathematical algorithms must be applied to amend any size differences (Cole & Richtsmeier, 1998). EDMA considered as a sort of traditional morphometric (TMM) extension, and have beneficial applications in some GMM settings (Cardini, 2012).

2.6.4 Thin Plate Spline (TPS)

Thin plate spline (TPS) "*is an interpolating function that can be used to deform the space between landmarks according to differences among pairs of landmark configurations. It is used to draw transformation grids*" (Rohlf, 2003). It is a user-friendly programmes. All TPS series, also called the Jim Rohlf TPS suite, can be downloaded free from http://life.bio.sunysb.edu/morph/, typically, it is for two dimensional (2D) analysis.

Recently, GMM techniques have been introduced to the field of anthropological analyses, especially the field of human evolution and forensic anthropology. During the previous decade, physical anthropologists extensively applied GMM approaches in their investigations (Ross *et al*., 2010; Kimmerle *et al.,* 2008; Gillick, 2012; Hadi, 2012). Formerly, GMM methods were primarily used in biological and biomedical sciences until Bookstein *et al.* (2004) argued that anthropological science may apply GMM techniques.

2.7 GMM Use in Forensic Anthropology and Human Identification

Since 2004, the fields of forensic anthropology and human identification have adopted the methods of GMM for research (Bigoni *et al*., 2010; Buck & Viðarsdóttir, 2004; Dabbs, 2010; Gonzalez *et al*., 2009; Kimmerle *et al.*, 2008; Nicholson & Harvati, 2006; Oettlé *et al*., 2005; Papaioannou *et al*., 2012; Pretorius *et al*., 2006; Ross *et al*., 2010; Scholtz *et al*., 2010; Sholts *et al*., 2011a; Sholts *et al*., 2011b). In forensic anthropology, most of the research relating to GMM has an emphasis on the analysis of sexual dimorphism using different bones, such as the cranium, mandible, or pelvic bones. Moreover, there is some literature involving analyses of the assessment of age at death and ancestry.

Oettlé *et al.* (2005) used two-dimensional GMM to study human mandibular rami as a single feature to decide whether significant differences exist between the sexes. The results illustrate that the mandibular ramus alone is insufficient for estimating unknown sex. Pretorius *et al.*

(2006) operated two-dimensional GMM methods to inspect sexually dimorphic characteristics by studying the greater sciatic notch shape, mandibular ramus flexure, and shape of the orbits from photographs. Predictably, the results of the Pretorius *et al.* (2006) showed that the shape of the greater sciatic notch is the most sexually dimorphic of all the morphological characteristics. However, the new result in the Pretorius *et al.* (2006) was that the shapes of the orbits differ between the sexes more than the shape of the ramus flexure. In general, for sex identification, the shape of the mandibular ramus was considered a more sexually dimorphic and reliable morphological trait than orbital shape (Loth & Henneberg, 1996). Gonzalez *et al.* (2011) used two-dimensional GMM utilizing landmarks and semilandmarks to look at sexual dimorphism in crania. Gonzalez *et al.* concentrated in detail on structures that are considered sexually dimorphic. The results demonstrate that there is a low level of sexual dimorphism in the shape of the cranium in terms of features such as the glabella region, mastoid process, and frontal and zygomatic processes. The cranium, though, is generally thought to be the second most useful measure of sex after the skeleton as much of the literature provides highly significant results using traditional metric techniques and morphological features of the cranium to determine sex (Suazo *et al*., 2008). However, when Gonzalez *et al.* (2011) combined shape and size variables to examine these traits, the calculation of the correct sex improved significantly, showing that the morphological traits exhibit noticeable sex differences correlating to the larger size and more vigorous features of males. GMM was therefore considered for use in this research in order to analyse the vermillion border outline along with the current guidelines used to predict the lips and mouth (Wilkinson, 2010).

GMM which are not yet commonly used in forensic identification, were used in recent projects by colleagues in Centre for Anatomy and Human Identification (CAHID) at University of Dundee (Gillick, 2012; Hadi, 2012; Hadi & Wilkinson, 2014). Gillik (2012) and Hadi (2012) described GMM as a powerful method and reported significant deficiencies in traditional approaches to forensic facial analysis. Therefore, GMM was used in this study along with photographic and cephalometric analyses. The main target of this GMM analysis is to measure and test variation in vermillion border morphology. It is necessary to identify vermillion border morphology variance within and between the malocclusion classes and whether this can be described in relation to measurement error.

So, in summary, the literature suggests that new guidelines for predicting lip shape from dental pattern would be of great benefit to forensic facial depiction from skeletal remains. Morphological and cephalometric analyses are well established methods for recording, measuring and comparing dental pattern and lip shape in dentistry, surgery and anthropology, and these methods will therefore be employed in this research to establish new standards. In addition, since morphological analysis is subjective and requires classification guides, the researcher will also utilise a new and more objective method for the analysis of shape (GMM) that has been employed previously for the analysis of biological variation and forensic anthropology.

Chapter 3
Research Design and Methodology

3.1 Study design

This is a cross sectional study examining retrospective facial data (radiographs and photographs) of two samples of orthodontic patients received treatment in Dental Hospital at Dundee University (Scotland) and Jordan University Hospital (Jordan). Three methods were utilised: cephalograms analysis, photographic analysis by morphological evaluation, and photographic analysis using geometric morphometric tools. In these methods different traits and anatomical landmarks were employed based on previous research methodology and the results will be valuable as templates within the fields of forensic facial reconstruction, maxillofacial surgery, orthodontics and plastic surgery.

3.2 Study Setting/Location

The study will be conducted in the Centre for Anatomy and Human Identification (CAHID) at University of Dundee in co-operation with the Dental school at University of Dundee where all the analysed data were supplied by the orthodontic department.

3.3 Ethical Statement

Ethical approval was granted from the institutional review board (IRB) and scientific committee at Jordan University Hospital (Number 2013/61) on 14/11/2013 for the use of Jordanians' image data from the Orthodontic Department (Appendix I).

For the Scottish sample, all clinical orthodontic records, including study models, radiographs and photographs with written consent taken at the Orthodontic Department of the University of Dundee Dental School are approved from an ethics perspective as per the conditions outlined in application 15/ES/0186 (Appendix I).

3.4 Study Material

The Jordanian data was sent digitally and included extra- and intra- oral photographs and cephalograms (Figure 3-1). Because of health insurance policy in Jordan most of the individuals who received orthodontic treatments are between11-14 years (Hamdan, personal communication), and as a consequence this was the age range used on this study.

***Figure 3-1**: Examples of the Jordanian patient data.*

Images source: Jordan University Hospital.

The Scottish subjects originated from the large database of pre-orthodontic treatment patients' files, radiographs, and photographs taken at the beginning of the orthodontic treatment. However, because a balanced was needed between the two studied populations, only 56 subjects were selected so as to match the number of the Jordanian sample set. The selected patients files contained: pre- treatment cephalogram, a set of extra- oral photographs of the patient's face in different poses (frontal, profile, and 45˚ views), and intra-oral photograph (Figure 3-2).

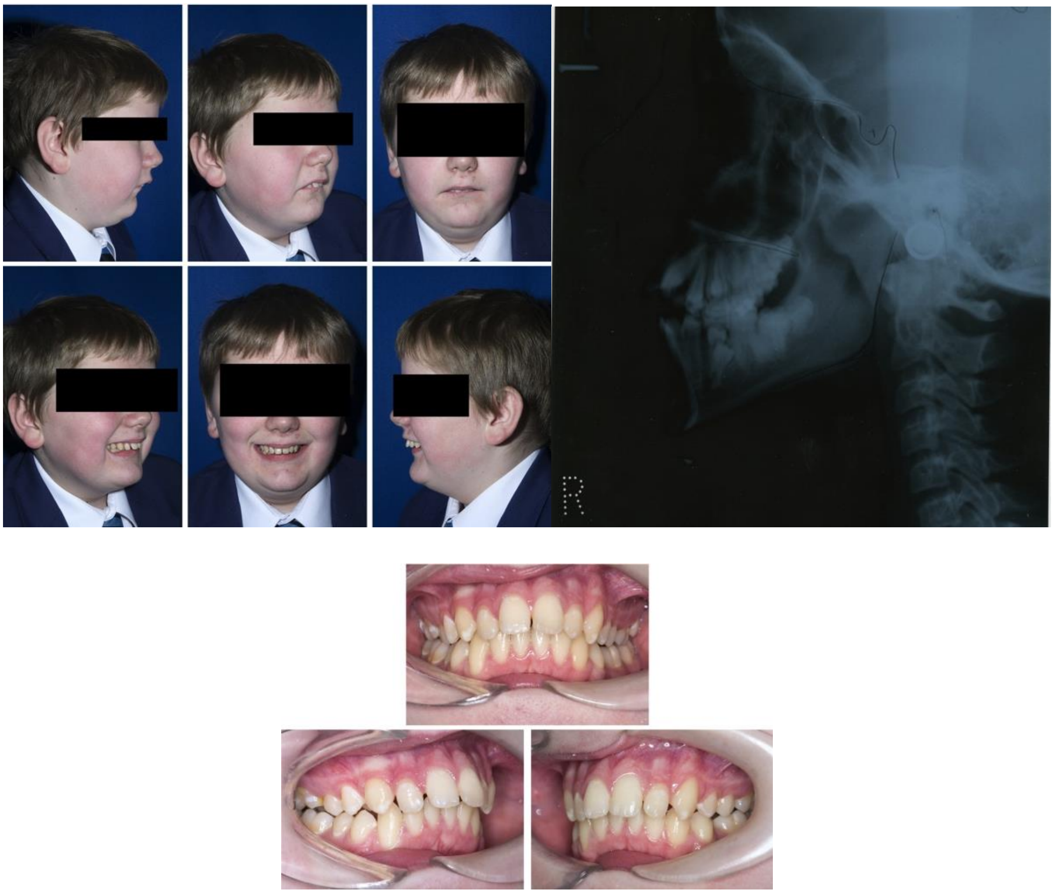


***Figure 3-2**: Examples of the Scottish patient data.*

Images source: Dundee Dental Hospital.

The Scottish sample consisted of 56 subjects (Table I-1- Appendix I), aged 11-14 years.

3.5 Subject Selection and Eligibility Criteria

The sample was selected based on the following inclusion criteria:

1- In order to limit the ethnic group variance; all subjects selected from Dundee Dental hospital were those who identified as white Scottish. The Jordanian subjects were selected based on place of birth and nationality from patient file so as to exclude other Arabic subjects.

2- The age of subjects was confined to 11-14 years.

3- All subjects had no previous orthodontic treatment or orthognathic surgery.

4- The permanent anterior teeth had erupted in all subjects. In addition, the maxillary and mandibular first permanent were fully erupted and not extracted.

5- The antero-posterior (Incisor classification) types of malocclusion were based on the British Standards Institute (BSI) classification: class I, class II division 1, class II division 2, and class III. All other malocclusion problems were excluded, for example: cross bite, open bite or scissor bite.

6- All subjects with severe skeletal malocclusion were excluded.

7- The selected photographs were of good quality. In the frontal pose; the subject had a neutral expression. For the profile photographs, the subject were selected as those with a neutral expression and position, based on subjective assessment of the researcher. Photographs were extracted from orthodontic departments of both Hospitals which followed a universal standardization photographic technique that included the patient’s position, distance from camera and amount of light. No further standardization was therefore necessary.

8- The Jordanian cephalograms were received in a standardized format whereas the Scottish data had a magnification error and a correction factor was used in order to standardize the cephalograms.

3.6 Study Procedures

3.6.1 Cephalograms Analysis

The cephalogram analysis was carried out using standardised cephalometric radiographs of the studied population. A number of angles and linear measurements were conducted and then compared between the two populations.

3.6.1.1 Landmarks choosing and Cephalograms tracing

After choosing the landmarks, which will be discussed in the following sections, the next step was tracing these radiographs. The tracing of the cephalometric radiographs was carried out manually using a sharp HB pencil on acetate tracing paper positioned over a light box in a darkened room. For intra-observer error analysis, each cephalogram was traced by the same assessor three times in a random order over an interval of two months. For inter-observer error analysis, two colleagues with dental backgrounds and training traced all the cephalograms twice at two-week intervals.

All of the cephalometric landmarks were located following the definitions and description of the cephalometric landmarks of Bhatia and Leighton (1993).

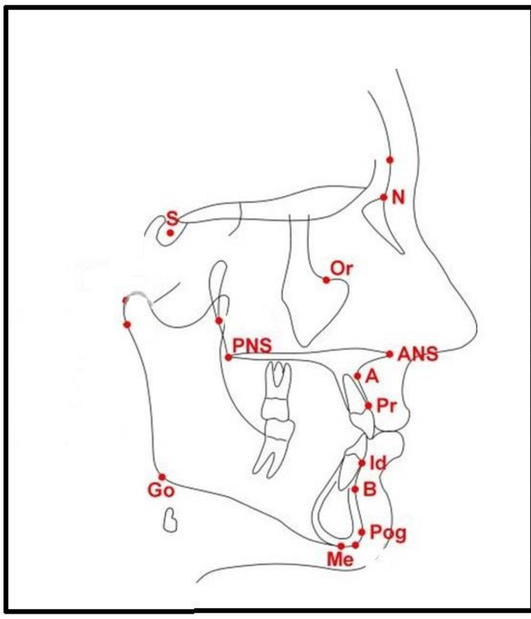
Errors associated with the placing of landmarks were assessed by using the first acetate tracing of each cephalogram as a reference and examining the consistency of landmarking on the subsequent tracing papers. This was done by superimposing each tracing onto the appropriate reference for each specific sample. This allowed any differences between each set of landmarks on the traces of the cephalograms to be measured and averaged. These average measurements between the same landmarks on different tracings were undertaken for all landmarks across all observers and allowed a statistical comparison to be made assessing both intra- and inter- observers' agreement using a paired t-test.

All of the Jordanian cephalograms were digital. The landmarks and measurements were digitised directly on the cephalograms using Adobe Photoshop CC 2014. The landmark error was checked using the Photoshop layers so that the 'reference' layer and the tracing layers could be directly compared.

All distance and angular measurements were transferred to tables in Microsoft Office and used for statistics analysis described in chapter four.

3.6.1.2 Skeletal and Soft Tissue Landmarks and Planes

In this analysis, 13 skeletal figure (3-3)

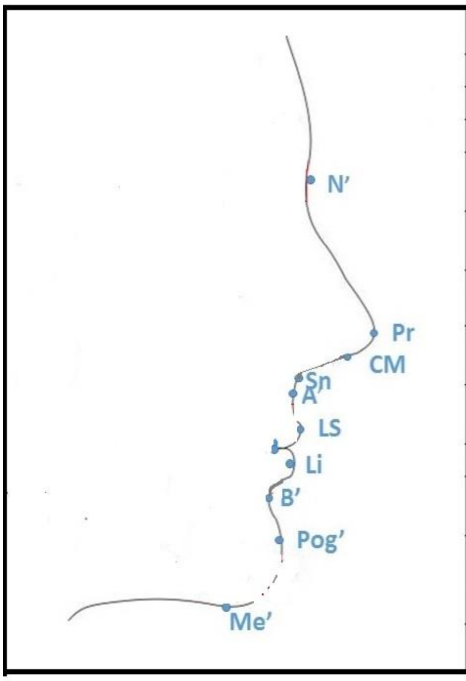


Skeletal landmarks
Sella (S)
Nasion (N)
Orbitale (Or)
Porion (Po)
Anterior nasal spine (ANS)
Posterior nasal spine (PNS)
A-Point (A)
Prosthion (Pr)
Infradentale (Id)
B-point
Pogonion (Pog)
Menton (Me)
Gonion (Go)

Figure 3-3: *Cephalometric skeletal tissue landmarks investigated in this study*

Source: Bhatia & Leighton, 1993.

In addition to 12 soft tissue variables were investigated Figure 3-4.



Soft tissue landmarks
Soft tissue nasion (N')
Pronasale (Pr)
Columella point (CM)
Subnasale (Sn)
Soft-tissue point A- A'
Labrale superior (Ls)
Upper lip stomion (Sts)
Lower lip stomion (Sti)
Labrale inferius (Li)
Soft-tissue B-point (B')
Soft-tissue pogonion (Pog')
Soft-tissue menton (Me)

Figure 3-4: *cephalometric Soft tissue landmarks investigated in this study*

Source: Bhatia & Leighton, 1993.

Table (3-1) defines landmarks that are fulcrum points in planes used in this study Definitions and abbreviations adapted from Bhatia & Leighton, 1993.

Landmarks	Definition	Plane
Sella (S)	The centre of the hypophyseal fossa (sella tursica)	Sella-Nasion line
Nasion (N)	The intersection of the internasal and frontonasal sutures.	Sella-Nasion line
Porion	A point on the human skull positioned at the upper margin of each ear canal (external auditory meatus, external acoustic meatus).	Frankfort horizontal plane
Orbitale (Or)	Located in the lowermost point on the inferior orbital margin.	Frankfort horizontal plane
Anterior nasal spine (ANS)	The anterior tip or point of the palatal plane or nasal floor.	Palatal or Maxillary plane
Posterior nasal spine (PNS)	The posterior tip or point on the bony hard palate or nasal floor.	Palatal or Maxillary plane
Gonion (Go)	The most posterior and inferior point on the outline of the angle of the mandible.	Mandibular plane
Menton (Me)	The most inferior point of the mandibular symphysis	Mandibular plane

***Table 3-1**: Hard tissue or skeletal landmarks used as fulcrum points in cephalogram analyses planes.*

More illustrations of these cephalometric planes are seen in Figure 3-5.

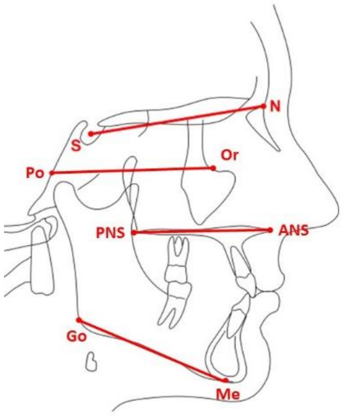


Figure 3-5: *Cephalometric planes used in this study. Sella- Nasion line (S-N), Frankfort horizontal plane joining Porion and Orbitale (Po-Or), Palatal/ Maxillary plane joining anterior and posterior nasal spines (ANS-PNS), and Mandibular plane passing through the lower mandibular border (Go-Me).*

Table 3-2 describes the other skeletal landmarks that were used in this study. It is worth noting that the first four points: point A, point B, Nasion and Pogonion in some orthodontic literature are considered as main landmarks for cephalometric planes.

Skeletal landmarks	Definition
A-Point	The deepest point on the arch between the ANS and prosthion.
B-point	The deepest point on the bony arch of the anterior border of the mandible; it lies between the infradentale and pogonion.
Pogonion (Pog)	The most anterior point on the outline of the bony chin.
Infradentale (Id)	The most superior anterior point on the mandibular alveolar process.
Prosthion (Pr)	The most inferior anterior point on the maxillary alveolar process.

Table 3-2: *The other skeletal landmarks employed in this study.*

These planes are: A-B plane, which links skeletal A and B points, and the Facial plane, which joins Nasion to Pogonion. Apart from these skeletal landmarks, 12 soft tissue landmarks were analysed and described in Table 3-3.

Landmarks	Definition
Labrale inferior (Li)	The point representing the vermillion border of the lower lip.
Labrale superior (Ls)	The point representing the vermillion border of the upper lip.
Pronasale (Pr)	The most protruding point of the tip of the nose.
Columella	The most anterior point on the columella, which is defined as the fleshy external end of the nasal septum.
Soft tissue menton (Me')	The most inferior point of the soft tissue in the chin.
Soft tissue nasion (N')	The deepest point of the concavity between the forehead and the soft tissue outline of the nose.
Soft tissue pogonion (Pog')	The most prominent point on the soft tissue outline of the chin.
Subnasale (Sn)	The point in the plane where the base of the columella of the nose meets the upper lip.
Soft Tissue A-point	The point of maximum concavity on the outline of the upper lip between subnasale and labrale superius.
Soft Tissue B-point	The point of ultimate concavity on the outline of the lower lip between labrale inferius and menton.
Stomion inferius/ Lower lip inferius (Sti)	The highest midline point of the lower lip.
Stomion superius/ Upper lip superius (Sts)	The lowest midline point of the upper lip.

Table 3-3: *Soft tissue landmarks investigated in this study.*

These landmarks linked to form specific “parameters” described in Table 3-4 to Table 3-6.

The total, anterior, and posterior facial height, in addition to nine facial angles were measured for each malocclusion class. Facial convexity was assessed by measuring the following angles were; (N'-Pr-Pog') angle to assess the total soft tissue convexity with the nose in facial profile, and soft tissue profile convexity (N'-Sn-Pog') (Ferrario *et al*., 2005; Coccaro & Pruzansky, 1965; Downs, 1948). The nasolabial angle (CM-Sn-Ls) was used to assess the degree of protrusion or retrusion of the upper lip, using the columella of the nose as a reference point (Holdaway, 1983; Fitzgerald *et al*., 1992; Nandini *et al.*, 2011; Dua *et al.*, 2010).

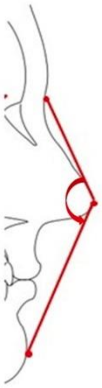
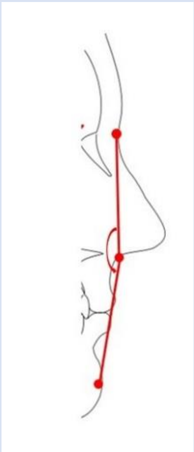
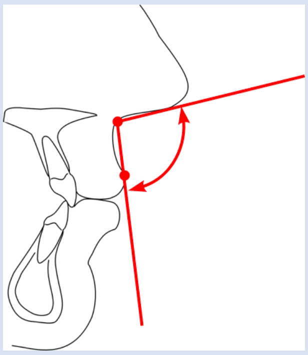
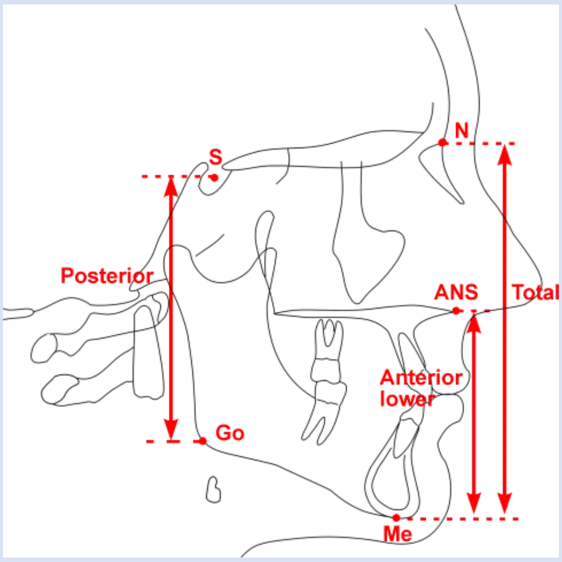
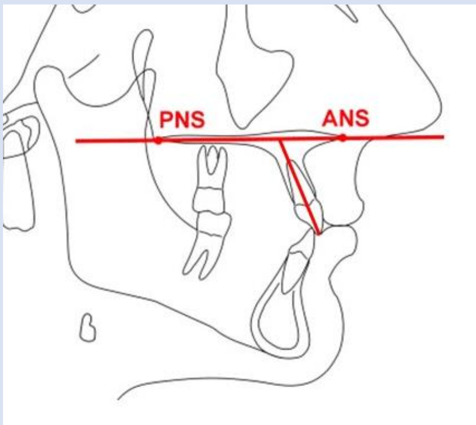
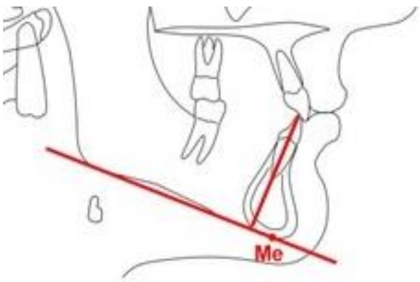
#	Parameter	Definition
1	N'-Pr-Pog' 	Angle of soft tissue convexity with the nose. The angle is formed by the lines joining the nasion, the most prominent point of the nose tip (Pronasale) and the soft tissue pogonion.
2	N'-Sn-Pog' 	Angle of soft tissue convexity without the nose. The angle is formed by the lines joining the nasion, subnasale and the pogonion soft tissue.
3	CM-Sn-Ls 	Nasolabial angle formed by the line joining the CM, Sn, and the most prominent point of the upper lip vermillion in the mid sagittal plane Ls.

***Table 3-4:** Cephalometric measurements to assess soft facial profile convexity and the nasolabial angle.*

Justification:

The measurement carried out on traced cephalograms included the facial soft tissue convexity parameters which were: the angle of total facial convexity (N'-Pr-Pog') angle of facial convexity (N'–Sn–Pog), and angle of nasolabial convexity (Cm–Sn–Ls), which evaluates the degree of protrusion or retrusion of the upper lip, in reference to the columella of the nose, as it is partially dependent on the anteroposterior position of the maxillary incisors (Isaacson & Thom, 2015). These angles, and related angles that used soft tissue glabella instead of soft tissue nasion, have been suggested and studied in several previous studies (Legan & Burstone, 1980; Powell & Humphreys, 1984; Graber, 1984; Bishara et al., 1995; Burston, 1967; Nanda et al., 1990), these studies aimed to evaluate the average variables that define the soft tissue facial profile of different populations and age groups, while the present study will assess the facial profile of different malocclusion classes from studied populations to assess and compare the results of norm standard of relevant studies, if present, and to add the average value to database used in forensic facial reconstruction to improve the present standards.

Facial height measurement and seven other angles were carried out in this analysis. These angles describes in Table (3-5).

#	Parameter	Definition
1	Facial height: anterior, posterior, and total 	The anterior lower facial height is the linear distance between the ANS and Me. The total anterior facial height is the linear measurement between N and Me. The posterior facial height is the linear measurement from S to Go. Note: Linear measurement from N to ANS represent the anterior upper facial height.
2	**UI – MX** 	The angle formed between the long axis of upper incisor (UI) and the maxillary plane (ANS-PNS).
3	**LI – MP** 	The angle formed between the long axis of lower incisor (LI) and the mandibular plane (Go-Me).

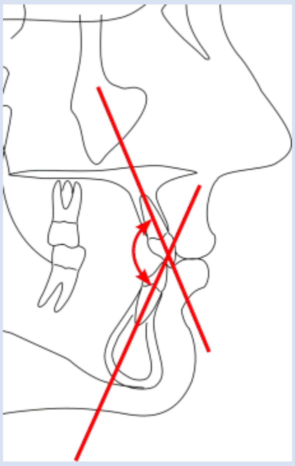
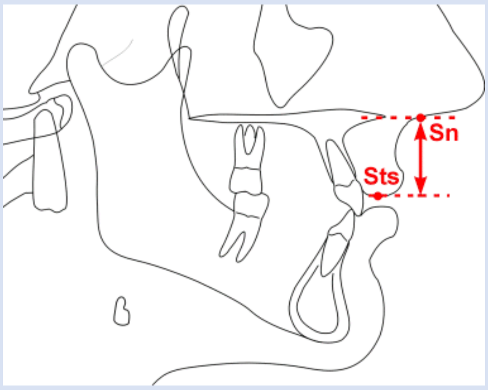
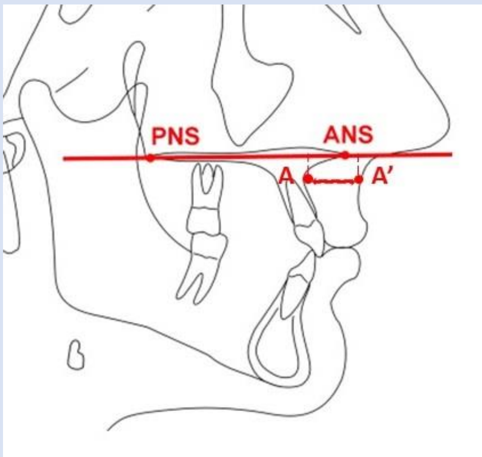
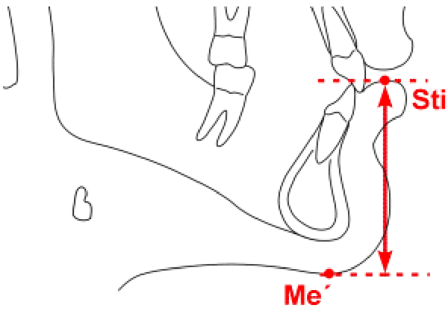
#	Parameter	Definition
4	**UI – LI** 	The interincisal angle formed by the intersection of the long axes of the maxillary and mandibular central incisors.

***Table 3-5:** Facial height measurements and incisors' angles analysis assessed in this thesis with illustration.*

Justification:

The upper and lower anterior, posterior, and total anterior facial heights were measured to calculate the percent ratio of lower anterior height over the total anterior facial height to assess and compare the relative proportionality of the anterior face in the vertical dimension of the four malocclusion classes. The measured angles were: (1) Upper incisor axis to maxillary plane angle (UI/MX) and (2) lower incisor axis to mandibular plane angle (LI/MN), which give the angulation of the upper and lower incisors to their relative skeletal bases. (3) Inter-incisal angle (UI/LI), which measures the degree of procumbence of the incisor teeth (Isaacson & Thom, 2015).

A further series of linear measurements (in mm) were recorded to estimate the upper and lower lip extent utilizing different landmarks to determine the accurate position of the lower and upper lips in the reconstructed face. These measurements described in Table (3- 6).

#	Parameter	Description
1	Sts-Sn 	Measurement of upper lip length from subnasale; this is done by measuring the true vertical line between the subnasale and the horizontal projection of the stomion superius/ upper lip stomion. This line is perpendicular to the Frankfort horizontal plane.
2	A-A’ 	Upper lip thickness by measuring a distance between point A and the to point soft tissue A’.
3	Sti-Me’ 	Measurement of lower lip length by assessing a vertical line from the stomion inferius/ lower lip stomion to the projection of soft tissue menton that referred to as point Me’.

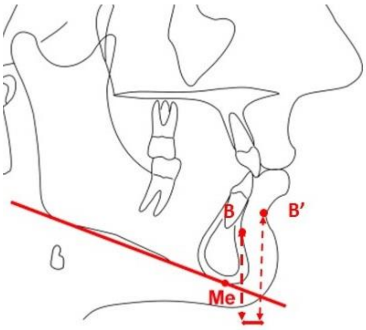
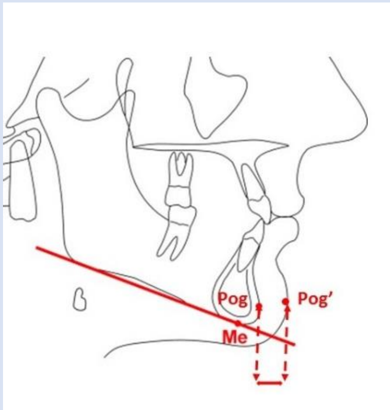
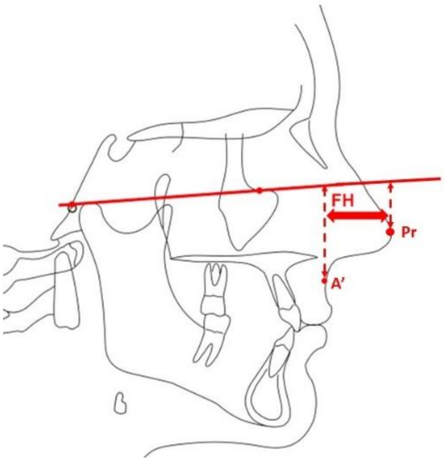
#	Parameter	Description
4	B-B’ 	Measurement of lower lip thickness by assessing a distance between the projections of point B point and the soft tissue point B’.
5	Pog-Pog’ 	To assess soft tissue chin thickness by measuring projection points of pogonion and soft tissue pogonion on the mandibular plane.
6	Pr-A’ 	To measure the nose depth by calculating the linear measurement between projections of the Pronasale and soft tissue A point on the Frankfort plane.

Table 3-6: *Cephalograms linear measurement to assess the length, thickness of upper and lower lips, plus the thickness of chin and the nose depth.*

Justification:

These linear measurements were used to statistically assess similarities or differences between different malocclusion classes across the study samples and the resultant information used to set scientific standards relating to the nasolabial morphology from dental pattern evaluation.

3.6.2 Photographic Analysis by Morphological Evaluation

In this analysis the "anatomical" lips are divided into two regions:

1. Upper lip area: The philtrum, Cupid's bow, and upper vermillion border were analysed and three morphological traits were classified from the photographs. Profile and frontal views were utilised where appropriate.
2. Lower lip area: Two traits were analysed in frontal and profile views.

3.6.2.1 Methodology

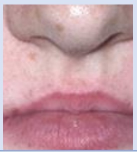
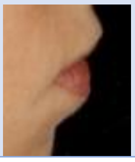
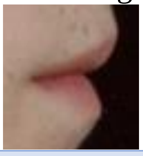
This analysis was based on scanned two-dimensional, pre-orthodontic treatment photographs of 56 Scottish subjects, using Epson Stylus Photo RX420 (M) scanner at 300 DPI as a pixel density, and the digital pre-orthodontic treatment photographs of 56 Jordanian subjects. Scottish and Jordanian subjects were aged between 11 and 14 years.

The selected photographs were selected based on researcher's subjective assessment of frontal view of subject's photograph. All photographs should display a neutral facial expression and of good quality. As the photographs used in this step in purpose for subjective morphological assessments no standardization was done for the photographs. To test the consistency of morphological trait assessments by the same observer (i.e. an intra-observer reliability test), the photographs were assessed by the researcher twice over a two month intervals. An inter-observer reliability test using two volunteers was conducted where the observers were first trained in cephalogram tracing and provided them with a reference handout explaining the traits which were to be recorded (Table 3-7). The volunteers then undertook the tracing activity twice across a two week interval.

3.6.2.2 Morphological Traits

For each subject the photographic materials were analysed and five naso-labial morphological traits were classified and the results were recorded using Microsoft Excel 2013. These traits were selected by the researcher based on the previous literature that related to the lip morphology. Table (3-7) shows a full description of the traits analysed.

Justification: These traits were studied, analysed, and linked to teeth shape or pattern devised in different previous studies as well as many reconstruction/ approximation approaches that rely on the teeth when the mouth area is constructed; examples of these studies: philtrum shapes and cupids bow shape (Krogman & İşcan, 1986, İşcan, & Helmer, 1993; Wilson *et al.*, 2012), lips fullness (Gerasimov, 1955; Wilkinson *et al.*, 2003), commissures shapes and positions (Krogman & İşcan, 1986; Stephan & Murphy, 2008; Wilkinson *et al*., 2003). Nevertheless, the precise shape of the vermillion line is challenging and difficult to determine (Wilkinson *et al*., 2006). Undeniably, there is wide variation in vermilion border thickness, outlines and contours, which may differ between sexes, ethnic groups, and even in the same individual, as the lip shape might be affected by the ageing process. For that reason, this study assess these traits (Table 3-7) with the purpose to explore and enumerate the correlations between different malocclusion types and vermillion border shape in the studied age group (11-14 years).

#	Morphological Trait	Explanation	Mark/ Score
1	Philtrum shape (frontal view)	The shape of the midline vertical groove that extends between the nasal septum and upper lip vermillion border assessed on a scale of 1 to 3.	1- Groove from columella extending through or to the vermillion border 
			2- Middle indentation 
			3- Smooth 
2	Cupid's Bow shape (frontal view)	A line in the middle of the upper vermillion border resembling the bow.	1- Flat 
			2- V-shaped 
			3- U-shaped 
3	Upper vermillion fullness (profile view)	Three categories based on the amount of pigmented area shown in profile photograph	1- Thin 
			2- Average 
			3- Thick

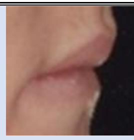
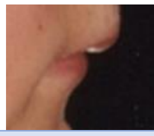
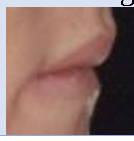
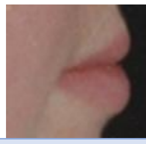
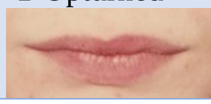
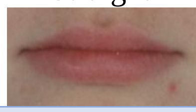
#	Morphological Trait	Explanation	Mark/ Score
			
4	Lower lip fullness (profile view)	Same as above	1- Thin 
			2- Average 
			3- Thick 
5	Commissures shapes (frontal view)	Progressive scoring of the angle of the mouth.	1-Upturned 
			2-Straight 
			3- Downturned 

Table 3-7: *Morphological Traits Assessed from Subject Photographs.*

3.6.3 Geometric Morphometric Evaluation of Lip Photographs

3.6.3.1 Recording of Lip Photographs

The materials analysed consisted of frontal view of photographs of pre-treatment orthodontic patients, from the two countries: Scotland and Jordan. These photographs are those previously used in the morphological analysis i.e. the two-dimensional, pre-orthodontic treatment photographs of 56 Scottish subjects, and the digital pre-orthodontic treatment photographs of 56 Jordanian subjects.

Shape information from the landmark and semilandmark coordinates was investigated using MorphoJ version 1.05f and a Generalized Procrustes Analysis (GPA). GPA was employed to register the coordinates and fit all individual photographs into a common coordinate system from which differences in size, translation and position are standardized (Klingenberg & Monteiro, 2005; Klingenberg, 2011). An average mean shape was produced for each malocclusion type and the landmark points captured from each case were translated to a common origin, rescaled to a unit centroid size, and rotated relative to one another to minimize the sum of squared distances between corresponding coordinates for all cases (Rohlf & Slice, 1990; Harvati, 2009; Weber & Bookstein, 2011). The centroid size, measured in centimetres, is a measure of dispersion around the centroid of the points in a landmark/semilandmark configuration (Klingenberg, 2011). After GPA was executed and the points were brought into a common coordinate system, the differences between the values of the coordinates of the landmarks provided a measure of the differences in shape between the cases (Slice, 2007; Klingenberg, 2011). GPA shape coordinates were subjected to statistical procedures to reduce the number of variables within the dataset, to discriminate between shape similarities and differences among and between malocclusion classes, and to categorise classes employing discriminant function analyses (Klingenberg, 2011).

3.6.3.2 Method of Shape Capture

All the images were already saved in Joint Photographic Experts Group (JPEGs, *.jpg) file extension format. For data manipulation and landmark digitization, these images were converted to * .tps files using the TPSUtil program. The seven landmarks were then placed in the same sequence on each image using TPSDig software. Semilandmarks (18 points) were digitized along certain structures and parts on the vermilion border, most importantly in the same sequence and with similar densities in each case. It should be stated that if semilandmark loci are employed in GMM research it is highly recommended that they be algorithmically repetitively or iteratively “slid” as an extension of the GPA method to perfect the correspondence between the loci and between cases (Bookstein, 1997; Perez *et al.*, 2006). By utilizing this technique, semilandmarks are permitted to perpendicularly “slide” until their positions are in line, and also to the analogous positions of points to a reference configuration (Perez *et al*., 2006). As all the data are two-dimensional semilandmarks, sliding was carried out using another TPS program, TPSRelw. In the final step before exporting the data for GMM analysis, all the TPS files were converted into NTS (.nts file extension) using the TPSUtil program. The landmark coordinates’ information stored in TPS and NTS formats was similar; however, data in NTS files are reorganized as rows and columns, where the rows conform to cases and the columns conform to coordinates. In some studies, the transformation to NTS is used as a shortcut for quick identification (Viscosi & Cardini, 2011).

3.6.3.3 Selection of points

To represent the vermilion border morphology, the Cartesian coordinates of seven anatomical points on the upper and lower vermilion borders and 18 semilandmarks were recorded. Due to the gross anatomy of lips, most of these landmarks were a series of semilandmarks, which are dots or loci on curvatures or surfaces, and were, correspondingly, used to achieve in-depth shape information on areas whose boundaries were defined by landmarks. The landmarks applied are listed and defined in (Table 3-8). Regarding their degree of homology and biological correspondence across the samples, seven (28%) could be considered to be type I landmarks, Figure 3-6, (points that have a clear well-defined histological location), and the contours or the border were outlined by 18 semilandmarks (72%) (Zelditch *et al*., 2004;

Hallgrimsson *et al*., 2007). A complete description of the curves and outlines marked by semilandmarks can be found in Figure (3-7).

Landmarks and semilandmarks were chosen primarily along upper and lower vermilion borders that reflect the variation experiential between different individuals. Such areas include the commissures (points marking the angle of the mouth). The link between these two points (right and left mouth angles) provides information about the mouth fissure shapes and commissure shapes. Moreover, it provides information about the width of the mouth aperture, cupid bow shape, and lower lip sub-vermillion median area, which is equivalent to the upper vermilion Cupid's bow. To capture a precise vermilion border contour semilandmarks were chosen so that they were straightforwardly recognizable on the curve of the lips and could be reliably repeated by researchers in addition to accounting for the variations that are more often seen between individuals.

Landmark order	Definition
1	Right mouth angle
2	Right point at the tip of Cupid's bow
3	Point at the base of Cupid's bow
4	Left point at the tip of Cupid's bow
5	Left mouth angle
6	Left point of the lower lip sub-vermillion median area
7	Right point of the lower lip sub-vermillion median area

Table 3-8: *Type I Landmarks on Upper and Lower Vermilion Borders.*

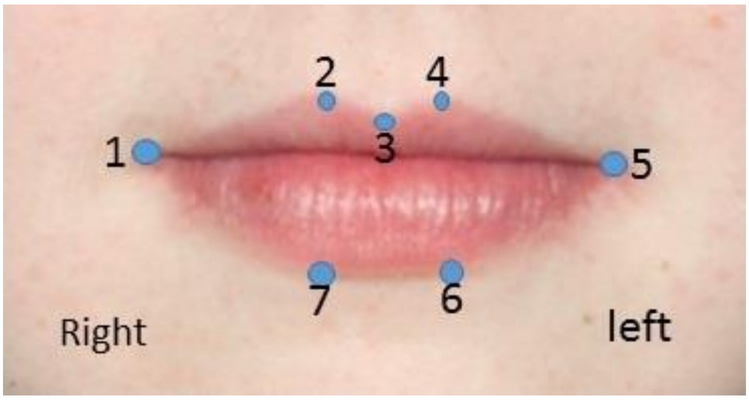


***Figure 3-6:** Frontal view of lips' vermilion border with the Type I landmarks.*

Source: Jordanian Data/ Jordan University Hospital.

3.6.3.4 Tracing of landmarks

After placing these seven landmarks, nine semilandmarks were traced on the outer rim of the upper and lower vermillion borders and a further nine semilandmarks were traced on the fissure of the mouth, as illustrated in (Figure 3-7) it is crucial to have an identical number of semilandmarks, "equidistantly spaced points along the curve" (Gunz *et al*., 2005). For patients with competent lips (Figure 3-7/B) some of these semilandmarks overlap especially in the mouth fissure. The error analysis for landmarks was assessed twice across a one month interval.

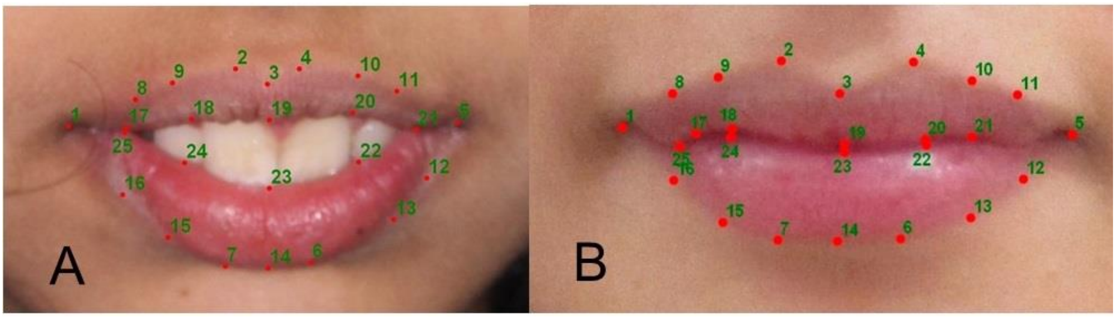


Figure 3-7: Frontal view of the incompetent lips (A) and competent lips (B) with landmarks and semilandmarks tracing the contour of the vermilion border and mouth fissure.

Source: Jordanian Data/ Jordan University Hospital.

Only three subjects from class II div 1 showed incompetent lips; therefore, these subjects were combined with the sample as their number was not enough to form a separate sample, and the results did not significantly affect the whole sample (Cardini, personal communication). The statistical consideration and results discussed in detail in the next chapter.

Chapter 4
Statistical Considerations, Data Analysis, and Results

4.1 Statistical Considerations and Data Analysis

4.1.1 Reliability and Error Analysis

The inter- and intra-observer reliability and agreement of the data assessment were evaluated. In the cephalogram analysis a paired t-test was used, provided that the differences in the dependent variables between the two related groups were normally distributed, and there were no significant outliers in the differences between the two related groups. If not, the Wilcoxon signed-rank test was used as the alternative non parametric equivalent to the paired t-test. The assessment of the internal consistency of a variable was by intraclass correlation coefficients (ICC: two-way random, absolute agreement). Reliability was considered to be acceptable if the ICC was greater than 0.75 and the 95% confidence interval (CI) was 0.3 or less.

For the morphological analysis, Cronbach's alpha was used to compute the internal consistency of each facial morphological traits. As there are more than two observers, weighted kappa (κw) was employed to estimate the intra- and inter-observers agreement.

For GMM analysis, measurement reliability was assessed by employing GPA and PCA on the sets of the landmark coordinates. Procrustes ANOVA was conducted on the shape coordinates of the error dataset to calculate the variation due to measurement error in comparison to the variation between individuals within the sample. PCA was performed to provide a visualization of how the replicated landmark configurations were plotted in relation to one another and to the entire dataset of all individuals from the studied sample.

4.1.2 Sample and Descriptive Analysis

IBM SPSS Statistics (version 21.0.0.0) was used for the statistical analyses. The first task was to examine the distribution of the data. The mean, median, and standard deviation of variables such as country of origin, sex, age, and malocclusion type were analysed.

4.1.3 Testing for Outliers and Normality

The Shapiro-Wilk test used to check normality and boxplot graphs were used to aid understanding of the distribution of the data and the detection of outliers. This step was significant to decide whether to use parametric tests or alternative non-parametric tests, as a common and crucial assumption in all parametric tests is that the dependent variable should be normally distributed for each group of the independent variable (Cleophas, 2009). However, tests such as the independent-samples t-test could be run regardless of the distribution of the data as "*because the independent-samples t-test is fairly robust to deviations from normality… In conclusion, non-normality does not affect Type I error rate substantially and the independent-samples t-test can be considered robust"* (Lund Research, 2015). Also, data that is not normally distributed does not necessarily force the investigator to use non-parametric statistics if a sample size is more than 30 (Revie, personal communication). In the cephalogram analysis and the morphological analysis, all the dependent variables: malocclusion class, sex, and country of origin; and the independent variables: cephalogram variables and morphological traits were tested for normal distribution for each combination of the group of independent variables.

For GMM, outliers were detected using MorphoJ. Another method to detect the outliers was performed using phenograms and a cluster analysis in PAST (*PA*leontological *ST*atistics version 3.05; downloadable free from http://folk.uio.no/ohammer/past/; last accessed 07/02/2015) (Viscosi & Cardini, 2011). In the phenogram tree (Figure 4-1) the distance between specimens in the tree is proportional to the difference between them. The figures that are most alike are on sister branches; those that are most different are remote from one another, and close to the root. Trees tend to distort shape distances (Viscosi & Cardini, 2011).

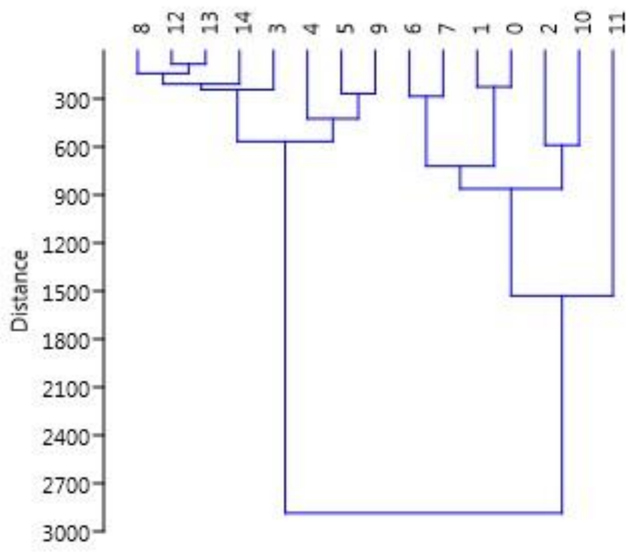


Figure 4-1: *A phenogram built using the paired group method with an arithmetic mean in PAST.*

The "index of cophenetic correlation" is a coefficient that "*measures the correlation between distance values calculated during tree building and the observed distance. The cophenetic correlation coefficient is a measure of how faithfully a dendrogram maintains the original pairwise distances*" (Felsenstein, 1993). Cophenetic correlation presented in PAST ranges between 1 (no distortion) and 0 (maximum possible distortion).

4.1.4 Frequencies and further statistical analysis

In the cephalogram analysis, the mean values for each measurement were calculated according to country of origin first. As the sample size in this step was more than 30 (i.e. N = 112), an independent-samples t-test, or one-way ANOVA test were used to determine whether there were any statistically significant differences between the cephalometric measurement means of the four malocclusion classes between the two populations. If there were no statistical differences between two populations, the data was then pooled for further analysis. The Mann-Whitney U test was used as the alternative when the sample size to be analysed less than 30, i.e. analysed a particular malocclusion. Then, the chosen test would be used to compare between malocclusion classes and the two sexes.

The frequencies of each morphological trait was calculated for a general overview and to assess distribution of certain traits in different malocclusion classes across the two countries. A Chi-squared test was used to assess the association of morphological traits and subject sex and then the associations between lip traits and malocclusion class would be assessed. Then, based on the distribution of the data a parametric or non-parametric statistical tests were used to assess the differences between the different malocclusion classes and the two populations.

For photographic analysis by GMM, first task was shape analysis by exporting the landmarks to MorphoJ version 1.05f (which can be downloaded free from http://www.flywings.org.uk/MorphoJ_page.htm; last accessed 07/02/2015) to carry out further statistical analyses. In MorphoJ, the same set of data were analysed differently based on the analytical focus, that is, sex dimorphism within the same malocclusion or between different malocclusions.

Secondly, landmarks and semi-landmarks were superimposition, this step was needed to achieve the best fit between homologous landmarks in and between all studied subjects, and was facilitated by scaling, translating, and rotating (Klingenberg, 2011). Scaling corresponds to the centroid size (CS), which is "*the square root of the sum of squared Euclidean distances from each landmark to the centroid, which is the mean of landmark coordinates*" (Dryden & Mardia, 1998). Principle Component Analysis (PCA) was then performed in MorphoJ and the variance covariance matrixes of the Procrustes shape coordinates were computed. PCA was applied in both analyses to explore intraspecific superimposition one malocclusion class at a time, and interspecific features between different malocclusion classes.

Analysis of variance (ANOVA) was used to measure and test variation in the vermilion border shapes between different malocclusion cases, and to see how much vermilion morphology difference there was within and among the same malocclusion class, as well as whether this was affected by country of origin.

The final step was to calculate and measure of the strength and direction of the association between the cephalometric variables (continuous variables) and the morphological traits (ordinal variables) by running the Spearman rank-order correlation test.

4.2 Data Analysis and Results

4.2.1 Inter-Observer and Intra-Observer Reliability Analysis

The consistency of both linear and angular cephalometric measurements across a single observer and across more than one observer in landmark placement was tested using a paired t-test ($p>0.05$) or the Wilcoxon signed-rank test depending on the normality or otherwise of the data.

4.2.1.1 Cephalograms Analysis

The reliability of the cephalometric measurements was tested by investigating the errors in all measurements across all subjects using the Wilcoxon signed-rank test (Appendix III- Table III-1- Table III- 4) showed that there were no significant differences between investigator and first observer (observer 1), investigator and second observer (or observer 2), and observer 1 and observer 2 ($p > 0.05$), which means the measurements were reliable and consistent between observers. The internal consistency of a variable was assessed by carrying out intraclass correlation coefficients, and the results suggested that the reliability was considered very good for all variables and in both studied populations as the ICC was greater than 0.90 and the 95% confidence interval (CI) was < 0.30.

4.2.1.2 Morphological Traits Analysis

For morphological traits analysis, the Cronbach's alpha reliability were computed, the results of Cronbach's Alpha for the main observer and observer 1 are presented in Appendix III (Table III-5 and Table III-6). The Cronbach's Alpha reliability coefficient results for the Scottish and the Jordanian samples were substantial and statistically accepted as good at $\alpha > 0.79$ across all traits.

The results of the intra- and inter-observer analysis, the weighted kappa test, are presented in Table 4-2 and Table 4-3. These results suggest that lip morphology classification was reliable for the same observer, as well as for between observers.

Malocclusion class	Intra-observer results	Inter-observer results (1)	Inter-observer results (2)
Class I	0.95	0.95	0.81
Class II div1	0.94	0.94	0.94
Class II div 2	0.95	0.95	0.85
Class III	0.95	0.85	0.85

***Table 4-1**: Kappa weighted reliability values for morphological traits in the Scottish sample.*
(1) = measurements by the investigator and the other observers.
(2) = the agreements between the two observers without including the investigator results.

Malocclusion class	Intra-observer results	Inter-observer results (1)	Inter-observer results (2)
Class I	0.96	0.95	0.81
Class II div1	0.95	0.94	0.94
Class II div2	0.94	0.94	0.85
Class III	0.95	0.85	0.85

***Table 4-2:** Kappa weighted reliability values for morphological traits in Jordanian sample.*

4.2.1.3 GMM Analysis

In GMM analysis, the results of the intra-observer error measurement study for landmark digitisation are presented in Table 4-4. No inter-observer measurements were carried out because the two observers who undertook the cephalometric and morphological analyses, had no experience in GMM tools.

	ICC	95% Confidence Interval		F statistic			
		Lower Bound	Upper Bound	Value	df1	df2	sig
Single Measures	0.990	0.979	0.996	297.486	18	36	0.000
Average Measures	0.997	0.993	0.999	297.486	18	36	0.000

Intraclass Correlation Coefficient (*ICC*), degrees of freedom (*df*), *F* statistic (F), and the associated *P*-value

Table 4-3: *Procrustes ANOVA results for landmark precision on 2D images.*

Results of the Procrustes ANOVA test indicated that individual variation from the landmark configurations demonstrated no significant differences for all shape and size interactions ($p < 0.001$). This indicates that landmark precision was accurate and repeatable. The tangent space approximation was tested by using TPSSmall. The importance of this step explained by Viscosi and Cardini (2011) *"this means that a distance between two observations is a straight line computed; however, because the Procrustes shape space is curved, it has to be approximated by a tangent Euclidean space using a projection computed as a cartographer would do to draw the curved surface of the Earth onto a flat map."* (Viscosi & Cardini, 2011). When the result of a regression with both slope and correlation almost equal to 1, the results of approximation were considered excellent. Therefore, the slope of the regression was calculated for each malocclusion class. The result of the Scottish class I was 0.998 with a correlation of 1.000. The mean distance, maximum, and minimum of procrustes shape to the Scottish class subjects were 0.0914, 0.1059, and 0.0698 units respectively. Similarly, the slope of regression for the Jordanian class I was 0.998 with a correlation of 1.000. The mean, maximum, and minimum Procrustes shape distances to the Jordanian class I subjects were 0.0829, 0.1319, and 0.0673 units of Procrustes shape distance respectively. The results of the other malocclusion classes are in Table 4-5. The results suggested that the approximation of vermillion border outlines superimposition in all malocclusion types were consistent.

Statistics for distance to reference	**All** Malocclusion classes
Slope	0.9961
Correlation	0.9999
Minimum	0.0516
Maximum	0.2799
Mean	0.1144

Table 4-4: *Regression through the origin for the distance in the tangent space.*

4.2.2 Descriptive Statistics

The studied sample consisted of 112 subjects, 50% (n = 56) males and 50% females, aged 11-14 years, with a mean age of 12.80 ± 1.03 years, and included four malocclusion classes with 28 subjects each class (class I, class II Div 1, class II Div 2 and class III). The sample consisted of two sub-samples Scottish sample and Jordanian sample each consisted of 56 subjects and included: 25% (*n* = 14) of each malocclusion class; 50% (n= 28) males and 50% (n=28) females. Subjects in both populations were aged 11-14 years; the mean age of the Jordanian sample was 12.75 ± 1.03 years, and for the Scottish sample was 12.79 ± 1.04 years. The age distributions of the Scottish and Jordanian samples are shown in Figure 4.2 & Figure 4.3. Descriptive results are shown in Appendix I (Table I-3 and Figures from I-1to I- 6).

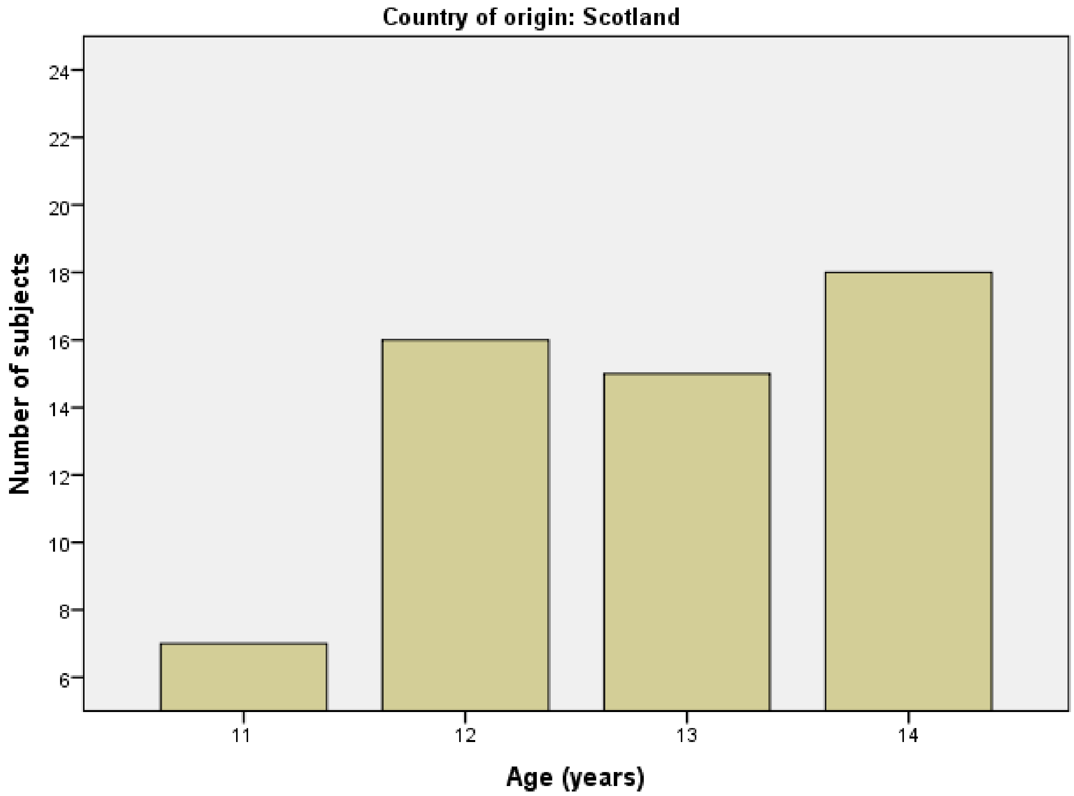


Figure 4-2: *Age frequencies of the Scottish subjects.*

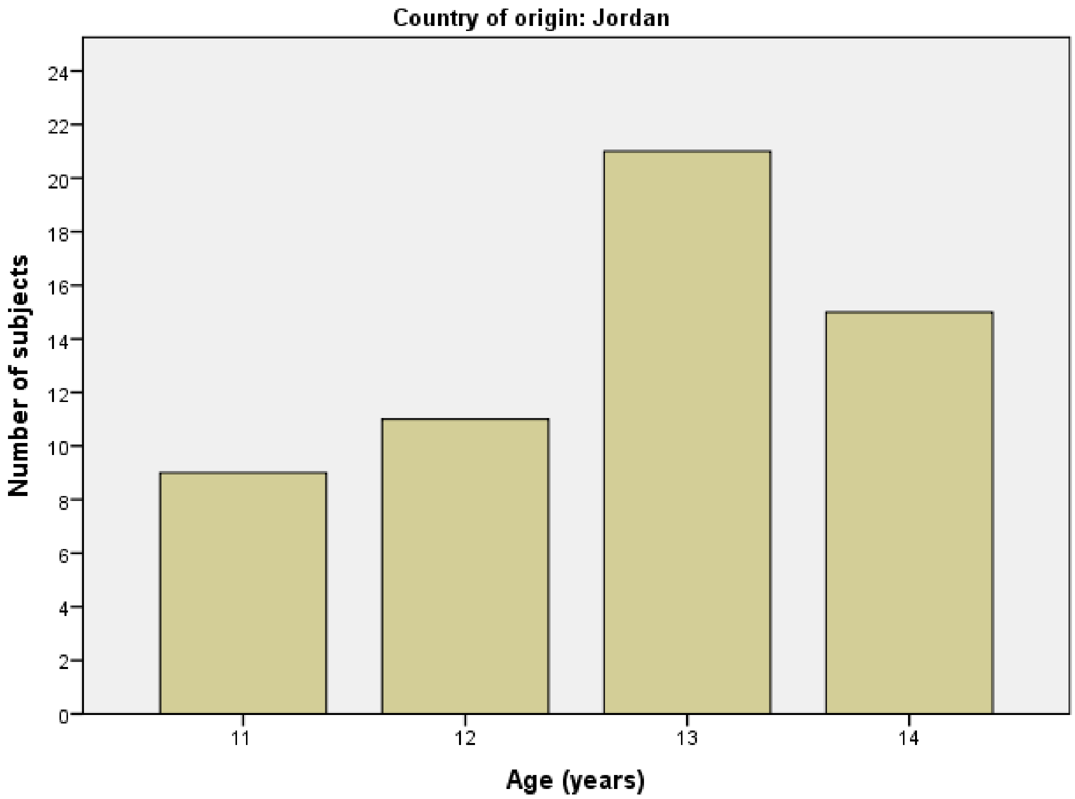


Figure 4-3: *Age frequencies of the Jordanian subjects.*

4.2.3 Testing for Outliers and Normality

The assumption of normality for cephalogram variable values and morphological traits scores was unsatisfied for the sample. The normality assumption of the data was tested by the Shapiro-Wilk test (results not displayed) to confirm these results. Outliers that were more than 1.5 box-lengths from the edge of the box in a boxplot, and extreme outliers that were more than 3 box-lengths were detected in some variables. All graphs of cephalogram variables are presented in appendix II. Example of these cases shown in Figure 4-4.

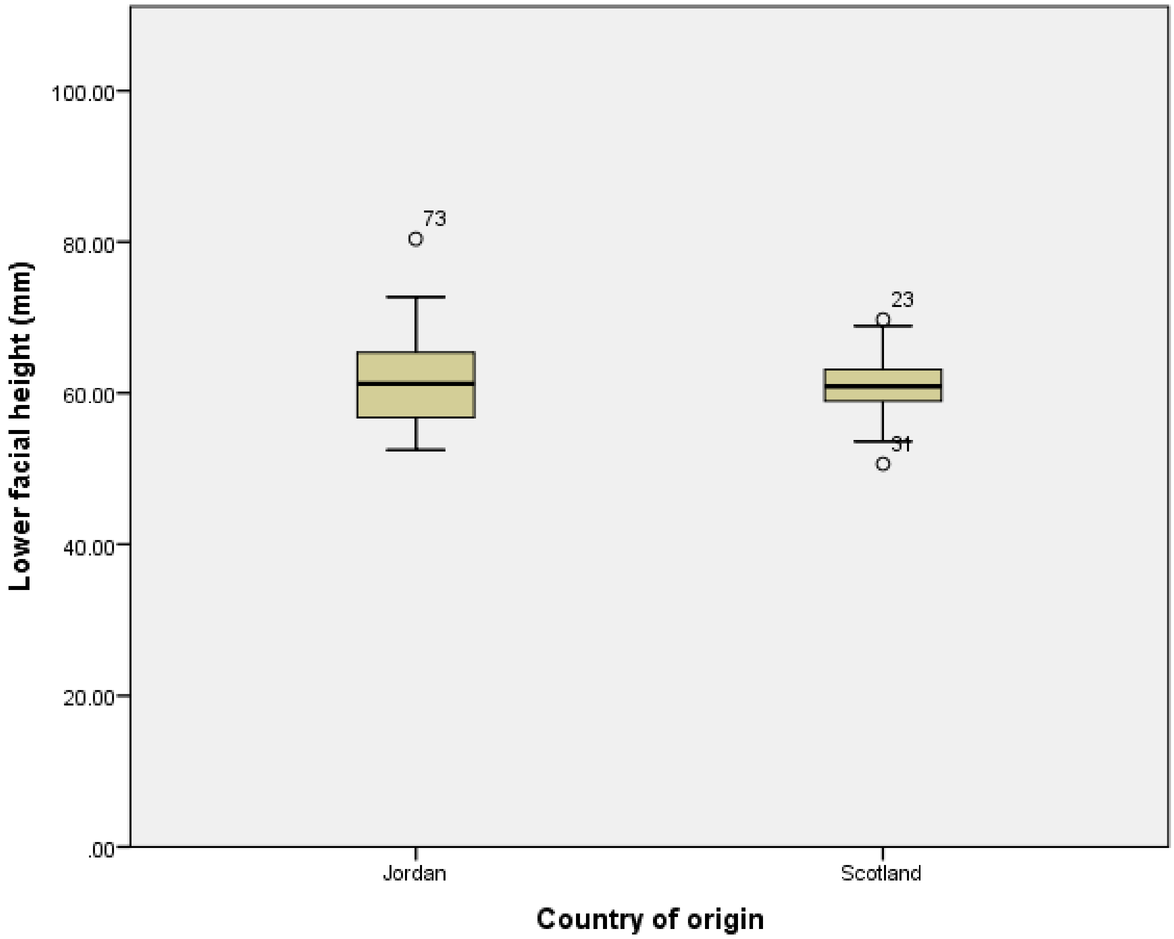


***Figure 4-4** : Boxplot for angle of lower facial height (mm) in whole sample as detected in country of origin: Scotland and Jordan.*

In Figure 4-4, two outliers were identified in the Scottish sample that were more than 1.5 box-lengths from the edge of the box, case number 23 had a larger value (i.e., 69.7 mm, *M* =

61.0 ± 3.9 mm) and case number 31 had a lower value 50.6 mm. One outlier was detected in the Jordanian sample that was more than 1.5 box-lengths from the edge of the box, case number 73 had a higher value (i.e., 80.4 mm, while *M* = 61.8 ± 5.7 mm). The outliers included in further analysis as their impact was minimal when examined using both non-parametric and parametric statistical tests.

In GMM analysis, a preliminary screening for outliers was computed in MorphoJ, and results revealed a good correspondence between the observed data and shape distances expected under a multivariate normal distribution model with no obvious outliers identified in all malocclusion classes. The index of cophenetic correlation was very high 0.8956 for the Scottish class I subjects and 0.852 for the Jordanian class I subjects indicating that there was no high distortion and the cluster fits quite well, that the selected landmarks were normally distributed and that no serious outliers affect the successive analysis. The results for the other malocclusion classes are shown in Table 4-1.

Malocclusion class	Scotland	Jordan
Class II div 1	0.9821	0.9076
Class II div 2	0.9164	0.9399
Class III	0.9463	0.9359
All	0.952	0.9474

Table 4-5: *Values of the index of cophenetic correlation for the different malocclusions in the Scottish and Jordanian datasets.*

4.2.4 Frequencies and Further Statistical Analysis

As a reminder, the first hypothesis states that: (A) the skeletal pattern in antero-posterior and vertical dimensions and (B) the upper and the lower incisor inclinations can predict the morphology of the soft tissue of the lips. The study hypothesis is the malocclusion class of subject can predict the lip shape and naso-labial morphology. Therefore, the null hypothesis (H_0) will be that there is no statistical difference between the type of the malocclusion and naso-labial morphology. Consequently, the subjects were classified to four malocclusion class based on the BSI definition of incisor relationship and the association between subjects with different malocclusion classes and morphological and cephalometric traits and variables were examined.

The second hypothesis is that the malocclusion class is more important than ethnic group to predict the nasolabial morphology. The null hypothesis (H_0) will be that the malocclusion class does not differ between different ethnic groups. This hypothesis was tested before starting any further analysis, this was carried out by examining the distribution of variables and traits across the whole sample for country of origin and sex.

4.2.4.1 Cephalometric Parameters Analysis According To Country of Origin

The independent-samples t-test was used to compare the means of the cephalometric parameters of the Jordanian and Scottish samples, in order to determine whether there was statistical evidence that the associated population means were significantly different. The independent-samples t-test is a parametric test. As the normal distribution (approximately) of the dependent variable, the cephalometric parameter, for each group is required to run the t-test and the data failed to fulfil this requirement, the results were confirmed by Mann-Whitney test, which produced similar results.

Mean and standard deviation values for each cephalometric value were computed according to country of origin (see Appendix IV - Table IV-1), i.e. the data were split and compared according to their country of origin. The cephalometric values that showed statistically significant differences are presented in table 4-6:

Cephalometric parameter	P-value
Nasolabial Angle	< 0.001
LI/MP	< 0.001
UI/LI	< 0.001
A-A’	< 0.001
Nose depth	0.045
Sti-Me’	0.016
B-B’	<0.001
Pog-Pog’	0.003

***Table 4-6**: The cephalometric parameters’ means that showed statistically significant differences.*

To test the effect of the malocclusion class in different cephalometric parameters, the means of the cephalometric parameters that revealed no significant differences between the two countries were pooled for any further analysis.

4.2.4.2 Cephalometric Parameters Analysis According To Subjects’ Sex

Similarly, the independent sample t-test and the Mann-Whitney U test were used to determine whether there were differences in the mean values of the cephalometric parameters between males and females (see Appendix IV- Table IV-2). Mean cephalogram variables values were not significantly different between males and females in most of the measurements, and these variables showed no sexual dimorphism. The parameters that were significantly ($p < 0.05$) different between males and females were:

- N’-Pr-Pog’, $p = 0.021$.
- Upper anterior facial height, $p = 0.009$.
- A-A’, $p = 0.003$.

The results showed that only upper lip thickness (A-A’) showed significant differences between the two populations ($p < 0.001$) and between the two sexes ($p = 0.003$). Therefore, the measurements that showed no significant differences were pooled for any further exploration.

4.2.4.3 Morphological Traits Analysis

As described in Table 3-7 each morphological trait has three scores. Based on subjective valuation, each trait for each subject was assessed and tabulated (see Table V-0/Appendix V). The differences in morphological traits between both populations, as a first step, were examined using a Mann-Whitney tests, as the variables were all ordinal, and the results are displayed in Table 4-6, revealing that the only significant difference was in upper lip fullness (p = 0.005). To assess the differences of the traits between different malocclusion classes, the data were pooled apart from the assessment of the upper vermillion fullness.

Morphological Traits	P-value
Philtrum shape	0.081
Cupid's bow	0.646
Upper vermillion fullness	**0.005**
Lower vermillion fullness	0.587
Commissures	0.224

Table 4-7: *Comparison of the various morphological features between the Jordanian and Scottish populations.*
Red denotes significant difference

A Mann-Whitney U test was used to examine the distribution of the morphological traits between sexes. The distributions of the morphological traits scores for males and females were not significantly different (see Table 4-7). These results allow pooling of the sexes for any further analysis.

Morphological Traits	P-value
Philtrum shape	0.861
Cupid's bow	0.912
Upper vermillion fullness	0.553
Lower vermillion fullness	0.914
Commissures	1.000

***Table 4-8:** Comparison of the various morphological features in the two sexes.*

4.2.4.4 GMM Analysis

For GMM analysis, raw data were imported in MorphoJ and procrustes superimposition was performed. In this analysis, the dataset fitting multiple groups: country of origin: Scotland and Jordan, sexes: male and female, malocclusion classes: class I, class II div 1, class II div 2, and class III. The effect of country of origin and subject sex accounted for lower percentage of the total sum of squares than malocclusion class effect (Table 4-8), however, the results for shape show the effect of sex was highly significant ($p < 0.001$). Therefore, it was important to divide the dataset according to sex, and country of origin to carry out more comprehensive analyses within the malocclusion classes.

Effect	%	SS	P
Country of origin	14.56	0.1245	0.000
Malocclusion class	82.15	0.4484	0.000
Subject sex	2.62	0.0783	0.000

(%) percentage effect of variable, (*SS*) procrustes sums of squares, and (P) P-value.

***Table 4-9:** Results of procrustes ANOVA for effects of general variation.*

4.3 Comparison between Different Malocclusion Classes

4.3.1 Soft Tissue Convexity

4.3.1.1 Angle of Total Soft Tissue Convexity (N'–Pr–Pog)

For the angle of total soft tissue convexity (N'–Pr–Pog) the differences were not statistically significant ($p = 0.939$) between Jordanian and Scottish subjects (see Table IV-1/ Appendix IV), and consequently the measurements were pooled for further analysis and comparison between malocclusion classes. However, the mean value for this angle showed significant differences ($p = 0.021$) between males and females, where this angle, regardless of the malocclusion class, was higher in females 132.4˚ ± 5.5˚ than males 130.1˚ ± 4.9˚. However, further analysis showed that there were no statistically significant differences in (N'–Pr–Pog) values between the different malocclusion classes, $F(3, 52) = 2.507$, $p = 0.069$ in females, and similar finding seen in males $F(3, 52) = 2.648$, $p = 0.059$. This meant that the total facial convexity was greater in females than males regardless of their malocclusion class.

4.3.1.2 Angle of Soft Tissue Convexity (N'-Sn-Pog')

The soft tissue convexity angle (N'-Sn-Pog') revealed that the differences were not statistically significant ($p = 0.154$) between Jordanians and Scottish subjects, and showed no sexual dimorphism ($p = 0.219$). Therefore, the measurements were pooled for assessing the difference between the malocclusion classes, and this was significantly different between malocclusion classes, $F(1, 54) = 5.041$, $p = 0.033$.

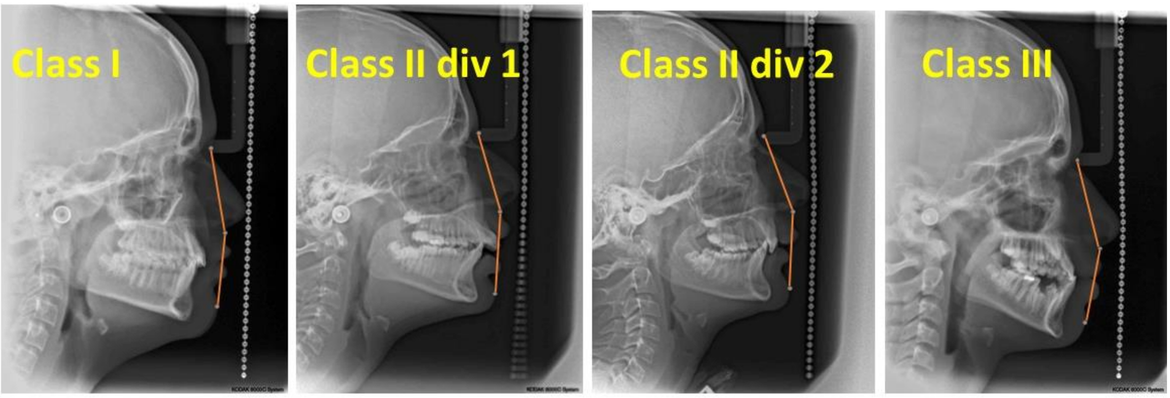


Figure 4-5: *A comparison of the N'-SN-Pog' (˚) angle in 4 male subjects from each malocclusion class.*

Source: Jordanian Data/ Jordan University Hospital.

Class III had the highest value (163.9˚ ± 6.9˚) with less convex facial profiles, while class II div1 had the lowest value (155.3˚ ± 5.9˚), with more convex facial profiles (see Table IV-3/Appendix IV). This should be taken in consideration while constructing or depicting the facial profiles of subjects with class II div1 malocclusion classes. These results were statistically significant ($p < 0.001$). Figure 4-5 displays a comparison of this angle between different malocclusion classes.

4.3.1.3 Angle of nasolabial Convexity (Cm-Sn-Ls)

The angle of nasolabial convexity (Cm–Sn–Ls) showed no statistically significant ($p = 0.547$) differences between males and females. However, the mean value of this angles showed a differences between the two studied populations ($p < 0.001$), where generally the mean value of this angle was lower in Jordanian (105.2˚ ± 10.6˚) than Scottish (113.6˚ ± 13.6˚) subjects. The nasolabial angle (CM-Sn-Ls) was higher in the Scottish class II div 1 subjects (119.9˚ ± 16.9˚), and the lowest value computed in the Jordanian class I (101.7˚ ± 11.8˚) and that difference was significantly ($p < 0.001$) computed in the Jordanian subjects, but there were no differences between malocclusion classes in the Scottish sample ($F (3, 52) = 0.942$, $p = 0.427$). (Table 4-9).

Malocclusion class	Statistics	CM-Sn-Ls (Jordan)	CM-Sn-Ls (Scotland)
Class I	Mean (˚)	108.2	111.2
	Std. Deviation (˚)	9.9	1.5
Class II Div 1	Mean (˚)	106.3	119.9
	Std. Deviation (˚)	9.5	16.9
Class II Div 2	Mean (˚)	104.6	117.2
	Std. Deviation (˚)	10.9	12.6
Class III	Mean (˚)	101.7	106.2
	Std. Deviation (˚)	11.8	14.5

Table 4-10: *The mean value of the angle of nasolabial convexity in malocclusion classes in the Scottish and the Jordanian samples.*

4.3.2 Incisors' Angles

In the following paragraphs the mean values of UI/MX, LI/MP, and UI/LI will be compared between the four malocclusion classes. As discussed in chapter three, these cephalometric angles measured the upper incisor axis to maxillary plane angle (UI/MX), lower incisor axis to mandibular plane angle (LI/MP), and inter-incisal angle (UI/LI).

Mean values for each measurement were illustrated according to country of origin and sex in Appendix IV (see Table IV-1, and Table IV- 2). These angles showed significant differences ($p < 0.001$) between the two studied populations except for: UI/MX ($p = 0.131$). However, there were no statistically significant differences between sexes. In light of these results the data were pooled for sexes and for country of origin (except UI/MX).

The upper incisor axis to maxillary plane angle (UI/MX) was an angle which was similar in the two populations and with no sexual dimorphism. The statistical analysis revealed significant differences between the four malocclusion classes ($F (3, 108) = 18.296$, $p < 0.001$), and class II div1 subjects had the higher value and class II div 2 showed the lowest value (Table 4-11).

Malocclusion class	Statistics	UI/MX
Class I	Mean (˚)	109.8
	Std. Deviation (˚)	5.7
Class II Div 1	Mean (˚)	114.8
	Std. Deviation (˚)	6.8
Class II Div 2	Mean (˚)	98.3
	Std. Deviation (˚)	12.8
Class III	Mean (˚)	110.2
	Std. Deviation (˚)	7.7

Table 4-11: *The pooled means of the cephalometric incisors' angle (UI/MX) comparison of different malocclusion classes.*

The mean values of LI/MP, and UI/LI showed significant differences (p < 0.001) between the two populations but no sexual dimorphism (Appendix IV- Table IV-1 and Table IV-2). One way ANOVA was run to detect the differences of mean values of these angles after splitting the data across the country of origin. In the Scottish sample (Table 4-10), the mean values of LI/MP, and UI/LI showed significant differences (p < 0.001) between the malocclusion classes. For the inter-incisal angle was highest in class II div 2 and the lowest value in class II div 1, which reflect the highest protrusion of anterior teeth in class II div 1 subjects, and consequently the convex facial profile.

Malocclusion class	Statistics	LI/MP	UI/LI
Class I	Mean (˚)	91.0	132.0
	Std. Deviation (˚)	0.9	1.9
Class II Div 1	Mean (˚)	91.1	121.6
	Std. Deviation (˚)	2.6	2.8
Class II Div 2	Mean (˚)	86.9	156.8
	Std. Deviation (˚)	1.6	8.7
Class III	Mean (˚)	76.0	147.6
	Std. Deviation (˚)	5.3	5.9

Table 4-12: *The pooled means of the Scottish cephalometric incisors' angles comparison of different malocclusion classes.*

In the Jordanian sample (Table 4-13), the value of LI/MP showed no significant differences between malocclusion classes ($F (3, 52) = 2.512$, $p = 0.069$). On the other hand, the interincisal angle UI/LI were significantly different ($F (3, 52) = 12.842$, $p < 0.001$) between the malocclusion classes in the Jordanians (Table 4-11). The interincisal angle value was higher in class II div 2 and the lowest value measured in class II div 1 subjects, this angle indicated the relationship between the upper and lower anterior teeth and might reflect the facial profile of these subjects.

Malocclusion class	Statistics	LI/MP	UI/LI
Class I	Mean (˚)	95.3	129.4
	Std. Deviation (˚)	4.6	4.9
Class II Div 1	Mean (˚)	98.4	113.9
	Std. Deviation (˚)	9.539	7.5
Class II Div 2	Mean (˚)	93.3	130.9
	Std. Deviation (˚)	7.5	11.6
Class III	Mean (˚)	91.2	121.1
	Std. Deviation (˚)	6.5	7.7

Table 4-13: *The pooled means of the Jordanian cephalometric incisors' angles comparison of different malocclusion classes.*

4.3.3 Facial Height

The mean measurements of TFH, LAFH, and PFH in the four malocclusion classes showed no differences between the two populations or the two sexes ($p > 0.05$) but only the upper anterior facial height (UAFH) showed significant differences ($p = 0.009$) between males and females. The pooled means are displayed in Table 4-14. Comparing the findings of (UAFH), using independent-sample t-test, according to sex revealed that, in females, the value was significantly higher ($p < 0.001$) in class I than other malocclusion classes. However in males

UAFH was higher in class II div 2, followed by class I ($p = 0.013$), which meant that males and females had different facial measurements based on their malocclusion class.

Cephalometric variable (mm)	M Class I	SD Class I	M Class II/1	SD Class II/1	M Class II/2	SD Class II/2	M Class III	SD Class III
TFH	108.3	3.8	107.5	7.3	108.8	5.8	107.4	5.3
UAFH (males)	49.0	1.7	46.3	4.9	49.2	3.6	45.5	3.8
UAFH (females)	47.8	2.2	46.1	3.5	46.3	2.8	42.3	3.4
LAFH	60.5	2.9	60.9	6.2	61.1	5.7	63.1	3.8
PFH	70.1	3.9	64.8	6.3	70.9	4.7	66.3	4.6

***Table 4-14**: Mean values of facial height measurements (mm) comparison between the four malocclusion classes.*

The statistical analysis revealed that TFH mean values were not different between the malocclusion classes ($F (3, 108) = 0.384$, $p = 0.765$). A similar finding was seen for LFH ($F (3, 108) = 1.665$, $p = 0.179$). However, the results for PFH were significantly ($F (3, 108) = 9.706$, $p < 0.001$) higher in class II div 2. In this study, the upper anterior and posterior facial height produced more statistically significant results for comparison between malocclusion classes than other facial measurements.

4.3.4 Upper Vermillion Border Measurements and Nose Depth

With regard to the upper lip linear measurements, there were significant differences in A-A' ($p < 0.001$), and nose depth ($p = 0.045$) between the two populations.

A-A', which measured the upper lip thickness, showed significant differences between males and females ($p = 0.003$), therefore further analysis showed that the A-A' was statistically ($p = 0.003$) higher in males (both populations) than females (both populations) Table 4-15. As this variable measures the upper lip thickness this indicated that males had thicker lips than females.

Cephalogram variable (mm)	Female/Scotland							
	M Class I	SD Class I	M Class II/1	SD Class II/1	M Class II/2	SD Class II/2	M Class III	SD Class III
A-A’	13.1	0.7	12.7	1.1	15.0	2.5	15.4	2.6
Male / Scotland								
A-A’	13.6	1.2	19.0	4.1	15.1	2.3	19.4	2.4
Female/Jordan								
A-A’	12.9	2.3	11.8	1.0	10.2	1.4	11.3	2.9
Male/Jordan								
A-A’	12.9	2.9	12.1	1.7	12.5	2.6	12.5	2.5

***Table 4-15:** Mean values of upper vermillion border (A-A’) measurements (mm) comparison between males and females in the four malocclusion classes in the Jordanian and the Scottish samples.*

The Pr-A’, which measures the linear distance between the pronasale and soft tissue A point, showed no differences between the sexes ($p = 0.355$), but showed significant differences ($p = 0.045$) between the two populations, being higher in the Scottish (16.6 ± 4.7 mm) than Jordanian (15.1 ± 2.9 mm) subjects. The nose depths showed significant differences between the malocclusion classes for Jordanian subjects ($F(3, 52) = 16.565$, $p < 0.001$), Table 4-16, with the highest value recorded in class I (16.3 ± 2.2 mm) and the lowest value recorded in class III (14.6 ± 3.1 mm). On the other hand, nose depth demonstrated no significant differences in the Scottish sample ($F(3, 52) = 1.225$, $p = 0.310$).

Malocclusion Class	Mean	Std. Deviation
Class I	16.3	2.2
Class II div1	14.7	2.7
Class II div2	14.7	3.3
Class III	14.6	3.1

***Table 4-16:** Mean values of nose depth (Pr-A’) measurements (mm) comparison in the four malocclusion classes in the Jordanian.*

The values of the upper lip length from subnasale (Sts-Sn) showed no differences between the two populations ($p = 0.279$), and no differences between the sexes ($p = 0.646$). Similarly, further analysis revealed no significant differences between the malocclusion classes ($F (1, 54) = 0.052$, $p = 0.820$) for Sts-Sn.

4.3.5 Lower Vermillion Border Measurements and Soft Tissue Chin Thickness

The lower vermillion border related measurements: lower lip length from soft tissue menton point (Sti-Me), lower lip thickness at B-point (B-B'), plus the soft-tissue chin thickness (Pog-Pog') showed there were significant differences between the two populations ($p = 0.016$, $p < 0.001$, $p = 0.005$, $p = 0.003$ respectively) but no sex differences ($p = 0.314$, $p = 0.353$, $p = 0.389$, $p = 0.213$ respectively). In light of these results male and female measurements were pooled. The differences between malocclusion classes in the Jordanian sample were statistically significant for these traits ($p < 0.001$, $p = 0.030$, $p < 0.001$, $p = 0.024$ respectively). The pooled mean values for Jordanian sample are displayed in Table 4-17.

Malocclusion class	Statistics	Sti-Me'	B-B'	Pog-Pog'
Class I	**Mean (mm)**	39.7	8.9	9.1
	SD (mm)	1.6	0.9	0.8
Class II Div 1	**Mean (mm)**	39.3	10.1	11.1
	SD (mm)	6.0	1.7	2.8
Class II Div 2	**Mean (mm)**	46.0	8.6	10.6
	SD (mm)	2.9	1.8	1.5
Class III	**Mean (mm)**	45.7	10.1	10.9
	SD (mm)	5.2	2.1	1.8

Table 4-17: *Mean values of lower vermillion border measurements (mm) and soft tissue chin thickness (mm) comparison between the four malocclusion classes in the Jordanian sample.*

The differences of these cephalometric measurements between malocclusion classes showed that lower lip length (Sti-Me') was the highest in class II div 2 (46.0 ± 8.6 mm) and the lowest value in class II div1 (39.3 ± 10.1 mm), ($F (1, 52) = 10.243$, $p < 0.001$). These finding showed differences of lower lip length between the two divisions of class II malocclusions, which indicate the necessity to assess the malocclusion class carefully before facial reconstruction.

Similarly, other lower lip measurements demonstrated differences between the two divisions of class II was the lower lip thickness (B-B’) was significantly higher ($F (3, 53) = 3.213$, $p = 0.030$) in class II div1 (10.143 ± 1.748 mm), where the lowest value was recorded for class II div2 (8.6 ± 1.8 mm).

The soft tissue chin (Pog-Pog’) was significantly ($F (3, 52) = 3.401$, $p = 0.024$) higher in class II div 1 (11.1 ± 2.8 mm), while the lowest value recorded in class I (9.1 ± 0.8 mm), which implied that class II div 1 Jordanian had thicker soft tissue chin than other malocclusion classes.

And for the Scottish sample the cephalometric variables: Sti-Me’, B-B’, Pog-Pog’ were statistically insignificant ($p = 0.283$, $p = 0.653$, $p = 0.145$ respectively).

4.3.6 Summary of Cephalometric measurements

- The cephalometric measurements in this study were repeatable and consistent between the observers, as shown by intra- and inter-observers reliability tests (Appendix III: Table III-1 to Table III-4).
- The angle of total soft tissue convexity (N’–Pr–Pog) showed no statistical differences between subjects according to their country of origin or malocclusion class. However, this angle revealed significant differences between the sexes, where this angle, regardless of the malocclusion class, was higher in females than males.
- The soft tissue convexity angle (N'-Sn-Pog') revealed no statistically significant differences between subjects according to their sex or country of origin but significant

differences between malocclusion classes. Class III had the highest value, while class II div1 had the lowest value.

- The nasolabial angle (Cm–Sn–Ls) revealed no statistically significant differences between the sexes. However, a difference between the two studied populations can be detected. The nasolabial angle (CM-Sn-Ls) was higher in the Scottish class II div 1 subjects, and the lowest value computed in the Jordanian class I.
- The mean value of upper incisor axis to maxillary plane angle (UI/MX) was higher in class II div 1 and lower in class II div 2 than the rest of malocclusion classes with no differences between the two populations and with no sexual dimorphism.
- The mean values of lower incisor axis to mandibular plane angle (LI/MP) and Inter-Incisal Angle (UI/LI) showed significant differences between the two populations and malocclusion classes, but no sexual dimorphism.
- Within the Scottish subjects, the inter-incisal angle was highest in class II div 2 and had the lowest value in class II div 1.
- Within the Jordanian subjects, the value of LI/MP showed no significant differences between malocclusion. But the interincisal angle UI/LI were significantly different. The interincisal angle value was higher in class II div 2 and the lowest value was measured in class II div 1 subjects.
- The mean measurements of facial height in the four malocclusion classes showed no differences between the two populations or the two sexes, except for the upper anterior facial height (UAFH) which showed significant differences between males and females. The class I females had a significantly higher value I than other malocclusion classes; however, in males UAFH was higher in class II div 2.

- The statistical analysis revealed that TFH and LFH mean values were not different between the malocclusion classes. However, the results for PFH were significantly higher in class II div 2.
- The upper lip thickness (A-A') showed significant differences between subjects according to sex and country of origin. A-A' was statistically higher in males (both populations) than females (both populations).
- The nose depth (Pr-A') showed no differences between the sexes. The nose depths showed the highest value recorded in class I and the lowest value recorded in class III. But the nose depth demonstrated no significant differences in the Scottish sample.
- The lower lip length (Sti-Me') showed significant differences between subjects according to their country of origin, but not their sex. Sti-Me' was the highest in the Jordanian class II div 2 and the lowest value in the Jordanian class II div1.
- The lower lip thickness (B-B') similarly was significantly higher in the Jordanian class II div1 and the lowest value was recorded for the Jordanian class II div2.
- The soft tissue chin (Pog-Pog') was also significantly higher in class II div 1, while the lowest value was recorded in class I.
- For the Scottish sample, the cephalometric variable results of: Sti-Me', B-B', Pog-Pog' were not statistically different between subjects according to their sex or malocclusion class.

4.4 Morphological Trait Analysis Using Photographs

Not all morphological features that help to predict lip shape were assessed using cephalometric variables. Therefore other traits were examined using morphological analysis by assessing frontal and profile photographs.

Non parametric tests were undertaken to compare the morphological traits between the differences/ similarities between the two populations within the same malocclusion class, males and females in the same malocclusion class. The pooled data were also assessed for any morphological trait difference within the malocclusion.

The results (Table 4-18) showed that there were no statistically significant difference between subjects according to their sex or country of origin except for upper lip fullness that differed between Jordan and Scotland.

Morphological Traits	Country of origin	Sex
	All malocclusion classes	All malocclusion classes
Philtrum shape	0.081	0.861
Cupid's bow shape	0.646	0.912
Upper vermillion fullness	0.005	0.553
Lower vermillion fullness	0.587	0.914
Commissures shapes	0.224	1.000

Table 4-18: *P-values of non-parametric test to assess the distribution of the morphological traits in both samples and sexes across malocclusion classes.*

Red results denote that this results is significant ($p < 0.05$).

A chi-square test was performed to assess the association between morphological traits and malocclusion class, results display in Appendix V (Table V-1 to V-23). Significant association were found in philtrum shape ($p = 0.013$) and cupid bow shape ($p = 0.006$); while, lower lip fullness ($p = 0.285$) and shape of commissures ($p = 0.609$) showed insignificant association.

4.4.1 Philtrum Shape

There were significant associations (p = 0.013) between philtrum shape and malocclusion types (Figure 4-6), the results showed that 57% of class I subjects were more likely to have a philtrum shape characterised with middle indentation and 79% of class III subjects had deep groove from columella extending through the vermillion border.

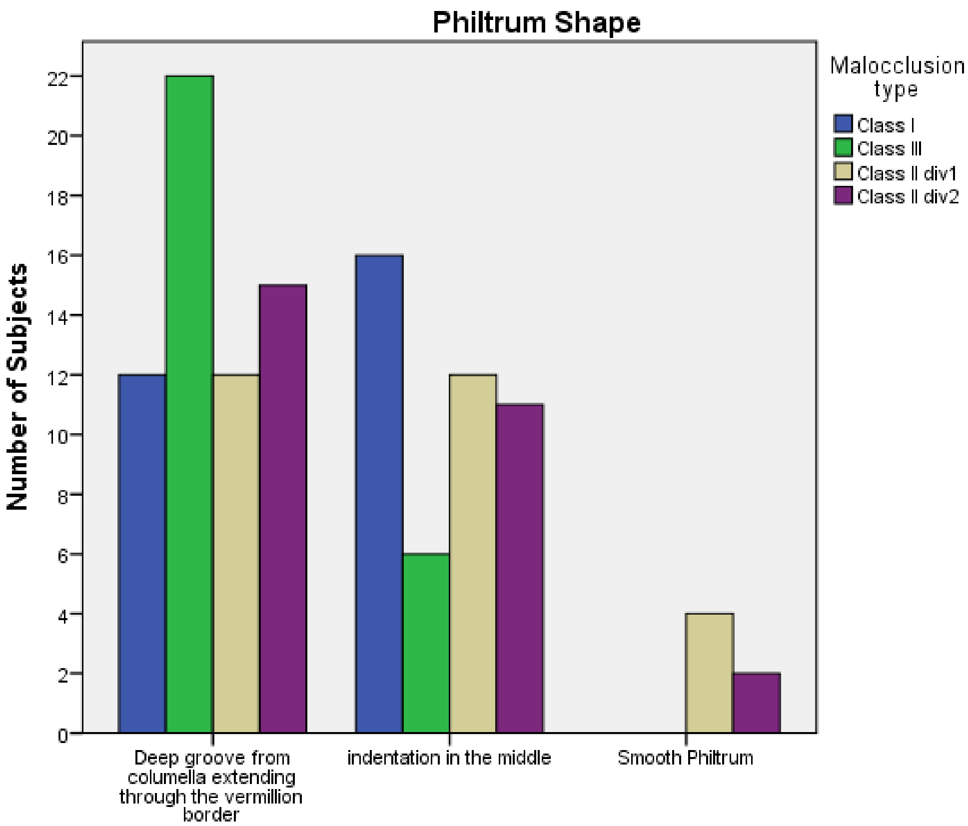


Figure 4-6: *The correlation between malocclusion class and philtral shape in the sample.*

4.4.2 Cupid Bow Shape

There were significant association between cupid bow shape and malocclusion class (p = 0.006). Class II div 1 (71%) and class II div 2 (64%) subjects were associated with the V-shaped cupid bow, this traits could be detected in class I subjects but in lower percentage (50%), while the flat cupid bow was associated with (50%) class III subjects, $p < 0.001$ (see Figure 4-7).

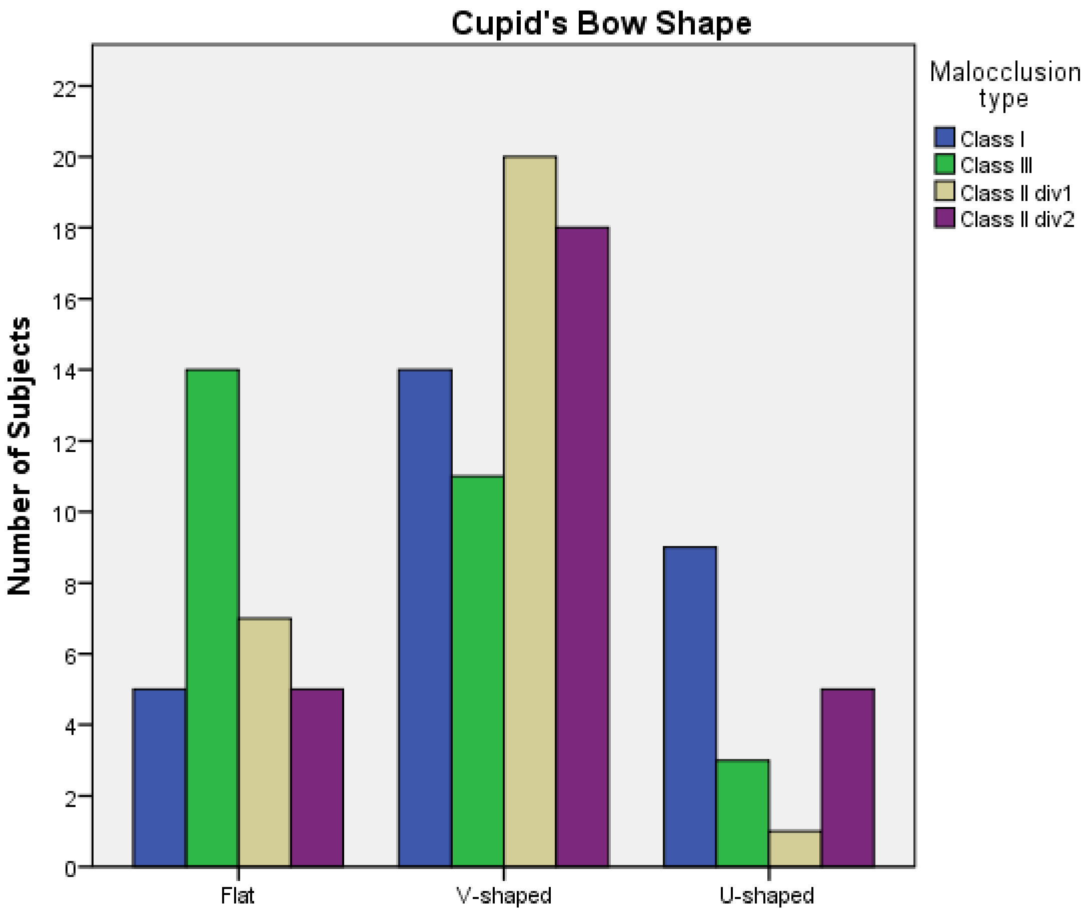


Figure 4-7: *The association between malocclusion class and cupid bow shape.*

4.4.3 Upper Vermillion Border

This trait showed significant differences ($p = 0.005$) between subjects from different countries, therefore, the prevalence of this trait was also assessed once the data was separated into two populations. There was a significant association ($p = 0.001$) between upper vermillion border fullness and malocclusion type for the Jordanian group. There was a 56.5% of individuals with average lips would be class III. Figure 4-8.

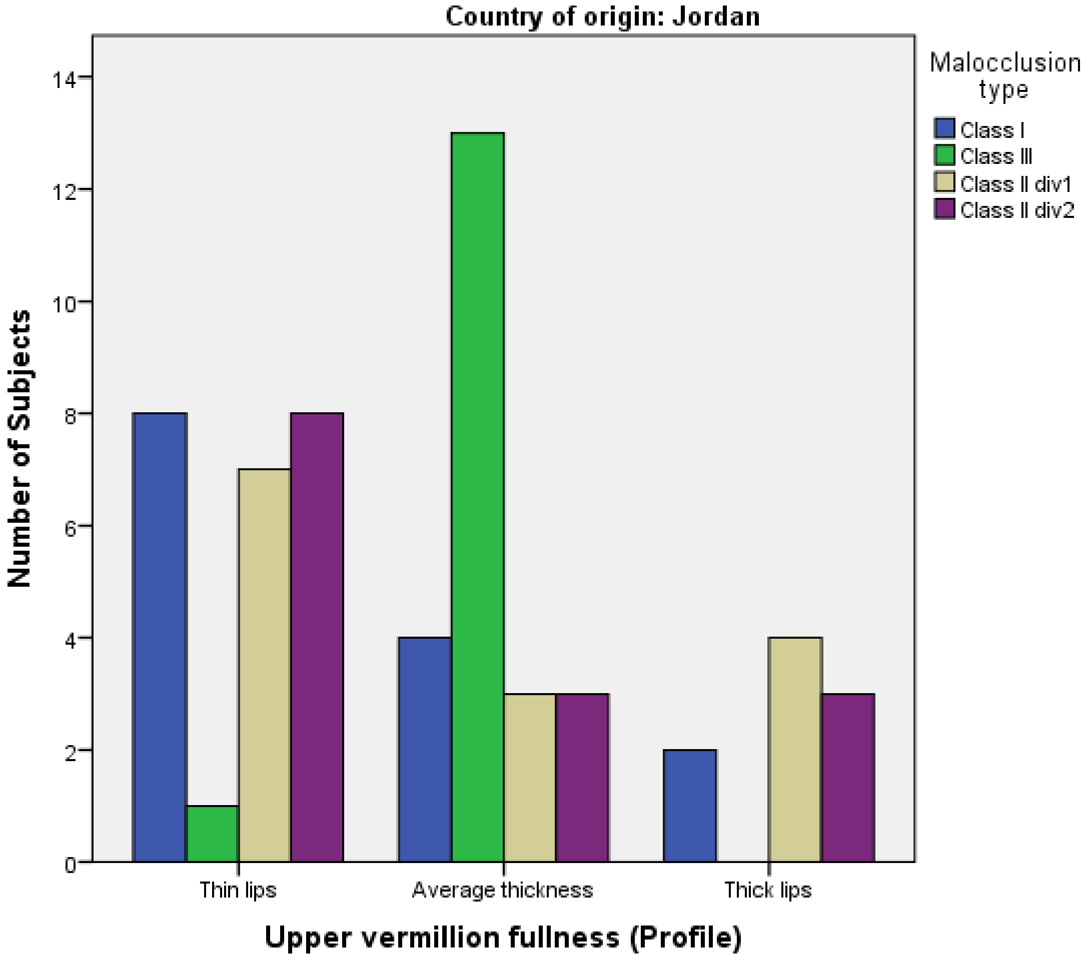


Figure 4-8: *The association between malocclusion class and upper vermillion fullness in the Jordanian sample.*

Similarly, there was significant association (p = 0.044) between the upper vermillion thickness and the malocclusion class. Thin upper lip fullness was a characteristic feature of Scottish subjects (Figure 4-9) with a class III and class I malocclusion.

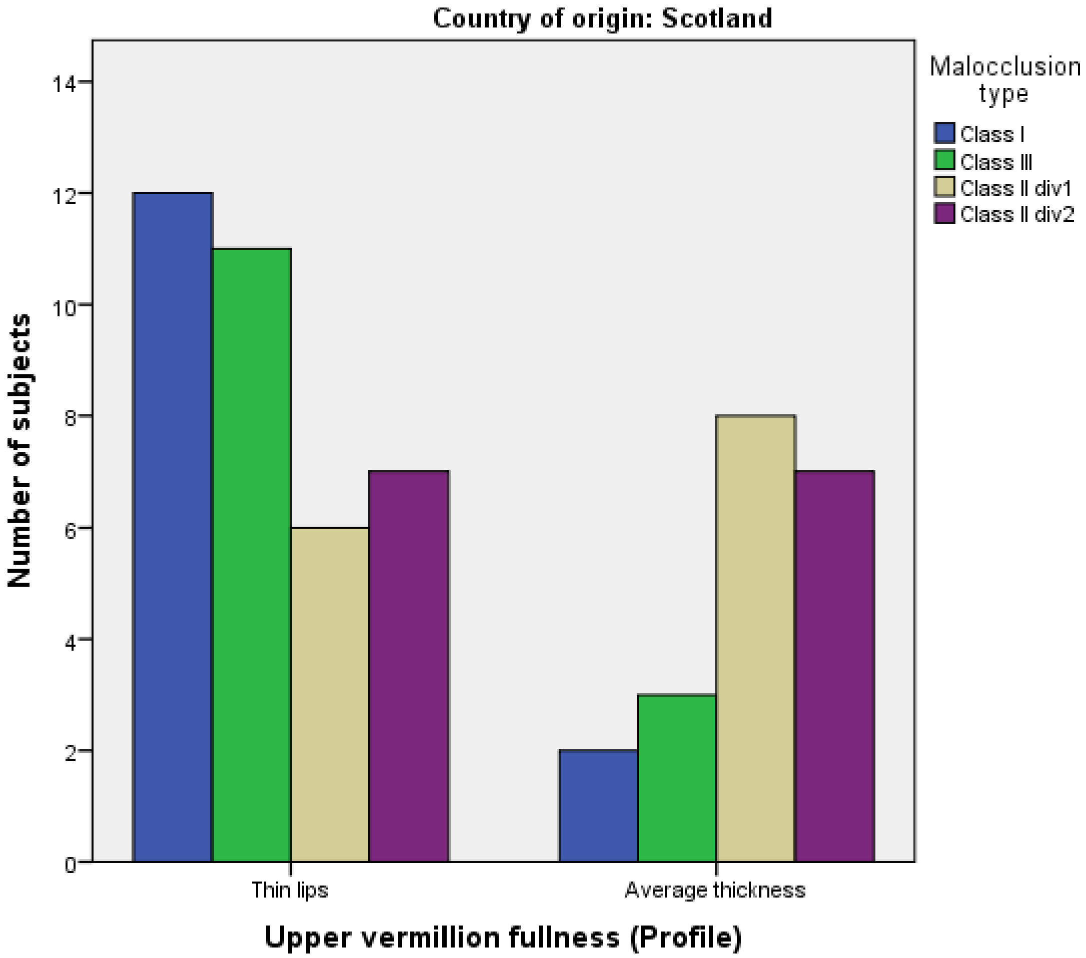


Figure 4-9: *The association between malocclusion class and upper vermillion fullness in the Scottish sample.*

4.4.4 Association between Different Morphological Traits

A chi-square test was performed to examine the morphological traits associations, to test the assumption that certain traits come together. The significant finding ($p = 0.007$) was recorded between philtrum shape and commissures shape, where a deep groove philtrum shape and straight commissures shape were associated, Figure 4-10.

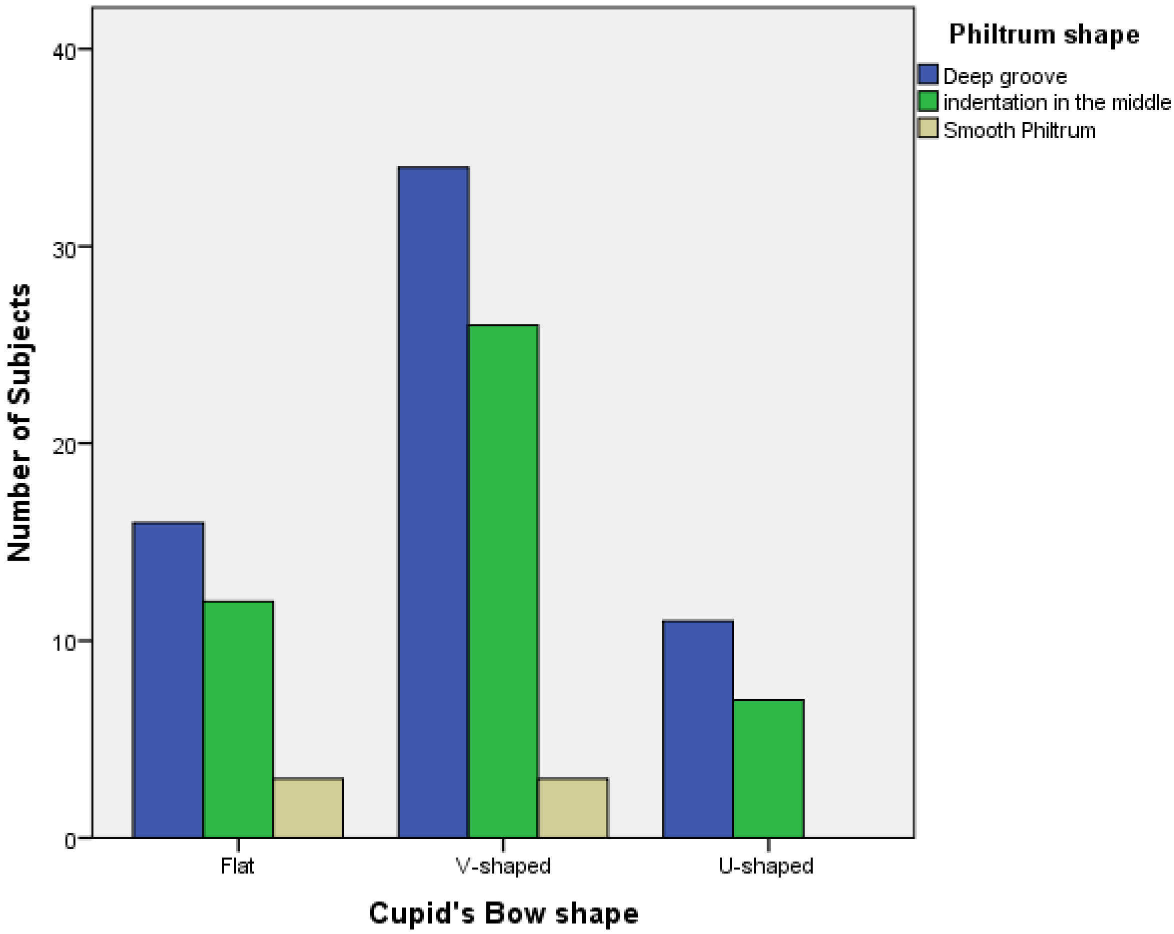


Figure 4-10: *The association between the philtral shape and the shape of commissures.*

There was an association between cupid bow and lower vermillion fullness. 61% with those who had flat cupid bow were more likely to have thin lower vermillion borders fullness, and 59% who had average lower lips had V-shaped cupid bow ($p = 0.019$). Figure 4-11.

In the Jordanian sample, there were significant association between upper lip fullness and other morphological traits, such as: average upper lip fullness and deep groove philtrum shape ($p = 0.023$). V-shaped cupid bow and thin upper lip ($p = 0.026$), and the association between thin upper lip with thin lower lips and average upper lip with average lower lip ($p = 0.011$). There was no significant association between upper lip fullness and commissures shape ($p = 0.309$).

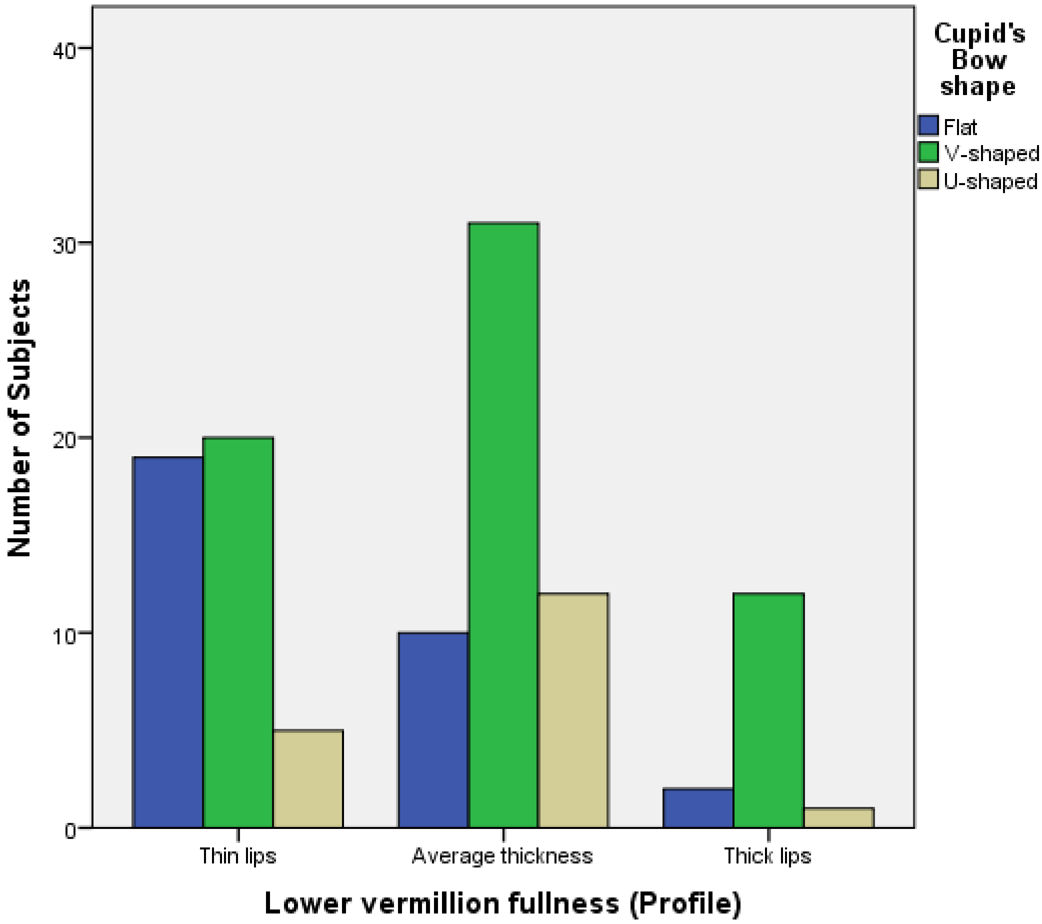


***Figure 4-11:** The association between the cupid bow shape and the lower lip fullness.*

In the Scottish sample, the only significant association could be seen between upper lip and lower lip fullness where the thin lips were associated and average lips associated together, Figure 4-12.

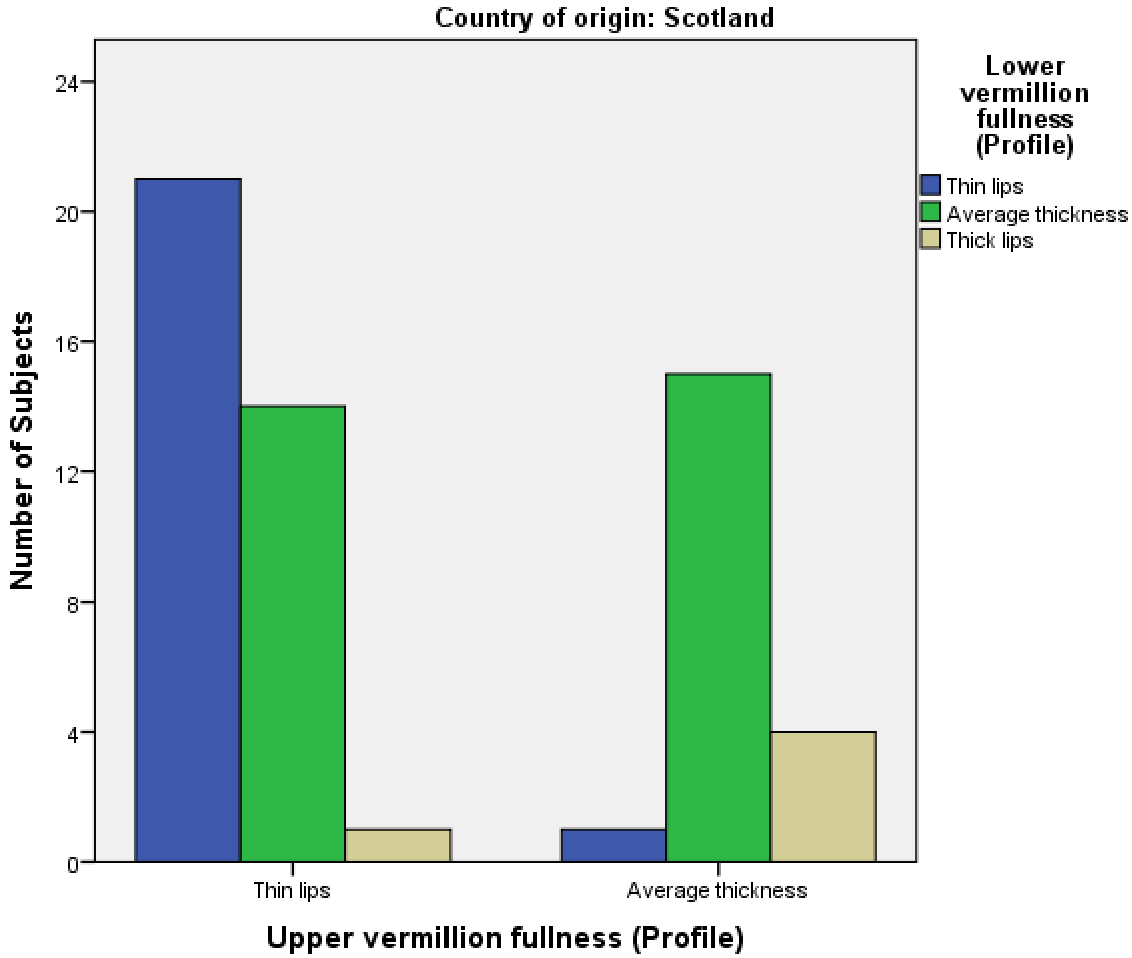


Figure 4-12: *The association between the upper lip fullness and the lower lip fullness in the Scottish sample.*

4.4.5 Summary of Morphological Traits Analysis

- The morphological traits had a good internal consistency, and the methodology was repeatable between observers as demonstrated with the intra- and inter-observers reliability tests (Table 4-1 and Table 4-2).
- Non parametric tests compared the morphological traits, and the results showed that there were no statistically significant difference between subjects according to their sex or country of origin except for upper lip fullness.
- The upper lip fullness showed significant differences between subjects from different countries of origin.

- Within the Jordanian group, there was an association between the class III individuals with average lips.
- Thin upper lip fullness was a characteristic feature of Scottish subjects with class III and class I malocclusions.

- A chi-square test was performed to assess the association between morphological traits and malocclusion class, and the results display significant association between philtrum shape and cupid bow shape; while, lower lip fullness and shape of commissures showed no significant association.
- Class I subjects (57%) were more likely to have a philtrum shape characterised with middle indentation and the majority (79%) of class III subjects had a deep groove from columella extending through the vermillion border.
- The majority of class II div 1 (71%) and class II div 2 (64%) subjects were associated with the V-shaped cupid bow, and this trait could be detected in class I subjects but in a lower percentage (50%), while the flat cupid bow was associated with (50%) class III subjects.
- A chi-square test was performed to examine the morphological traits associations. There was a significant correlation between the philtrum shape and the commissures shape, where a deep groove philtrum shape and straight commissures shape were associated.
- There was an association between the cupid bow and the lower vermillion fullness. 61% of those who had a flat cupid bow were more likely to have thin lower vermillion borders fullness, and 59% who had average lower lips had V-shaped cupid bow.
- Within the Jordanian sample, there were significant associations between the upper lip fullness and other morphological traits, such as: (1) the average upper lip fullness and the deep groove philtrum shape, (2) the V-shaped cupid bow and a thin upper lip, (3)

a thin upper and lower lips and (4) an average upper lip with an average lower lip. There was no significant association between upper lip fullness and the commissures shape.

4.5 Testing Variation Using GMM analysis

The main aim of this GMM analysis was to measure and test variation in vermillion border morphology to establish how much the morphology differs within and between the malocclusion classes.

The results for vermillion border shape showed that the effects of malocclusion, country of origin, and sex were highly significant ($p < 0.001$). The malocclusion classes explained 82% of that effect. Country of origin and sex effect on morphology differences were small (4% & 3% respectively) (Table 4-17).

Main Variable	%	SS	MS	F	P- value
Country of Origin	4.18%	0.1245	0.002708102	6.26	<0.0001
Malocclusion	82.15%	0.4484	0.000277229	2.02	<0.0001
Sex	2.62%	0.0783	0.001701839	3.9	<0.0001

Procrustes sums of squares (*SS*), Procrustes mean squares (*MS*), Goodall's *F* statistic (F), and *P*-value.

Table 4-19: *procrustes ANOVA for effects of main variables on vermillion border shape.*

The size of each vermilion border outline was assessed and evaluated as the square root of the sum of the squared distances of each landmark (SS in Table 4-18). Size was found to be significantly correlated to malocclusion class, sex, and country of origin; however, the effect of country of origin and sex were very minimal (Table 4-19).

Effect	%	SS	MS	F
Country	0.91%	8879118.82	8879118.82	810.47
Malocclusion	90.34%	5876051.81	30604.43	3.82
Sex	0.0003%	56.26	56.26	0.01
2nd measurement	0.067%	10955.53	10955.53	0.09
Residual	8.67%	1401932.51	116827.70	

Procrustes sums of squares (*SS*), Procrustes mean squares (*MS*), degrees of freedom (*df*), Goodall's *F* statistic (F), and the associated parametric *P*-value

***Table 4-20**: Results of procrustes ANOVA for effects of main variables on the centroid size.*

Size was the largest for class II div 1, followed by those for class III, class II div 2, and class I respectively. The male group had slightly larger lips' sizes than the female group.

Variable	SS	TSS	P- value
Jordan	1.642	1.600	<0.0001
Scotland	1.259	1.259	<0.0001
Class II div 1	1.045	1.016	<0.0001
Class II div 2	0.775	0.757	<0.0001
Class III	0.898	0.881	<0.0001
Class I	0.226	0.224	<0.0001
Male	1.602	1.561	<0.0001
Female	1.371	1.344	<0.0001

***Table 4-21**: Procrustes sums of squares (SS) and Tangent sums of squares (TSS) of different variable.*

4.5.1 Vermillion Border Shapes Differences among Malocclusion Class

GMM showed that the differences between the vermillion border shapes between the same malocclusion classes from the two studied populations were minimal and mainly related to size rather than shape (Table 4-18). For subjects from the both studied populations of different malocclusion class, there were no differences in mouth width, however, the Jordanian subjects had slightly more upper and lower vermillion border height.

As the malocclusion class described 82% of variation in lip morphology the data was pooled by country and sex as their effect on lip shape was negligible. Using the discriminate function analysis the lip outlines in different malocclusion classes were compared.

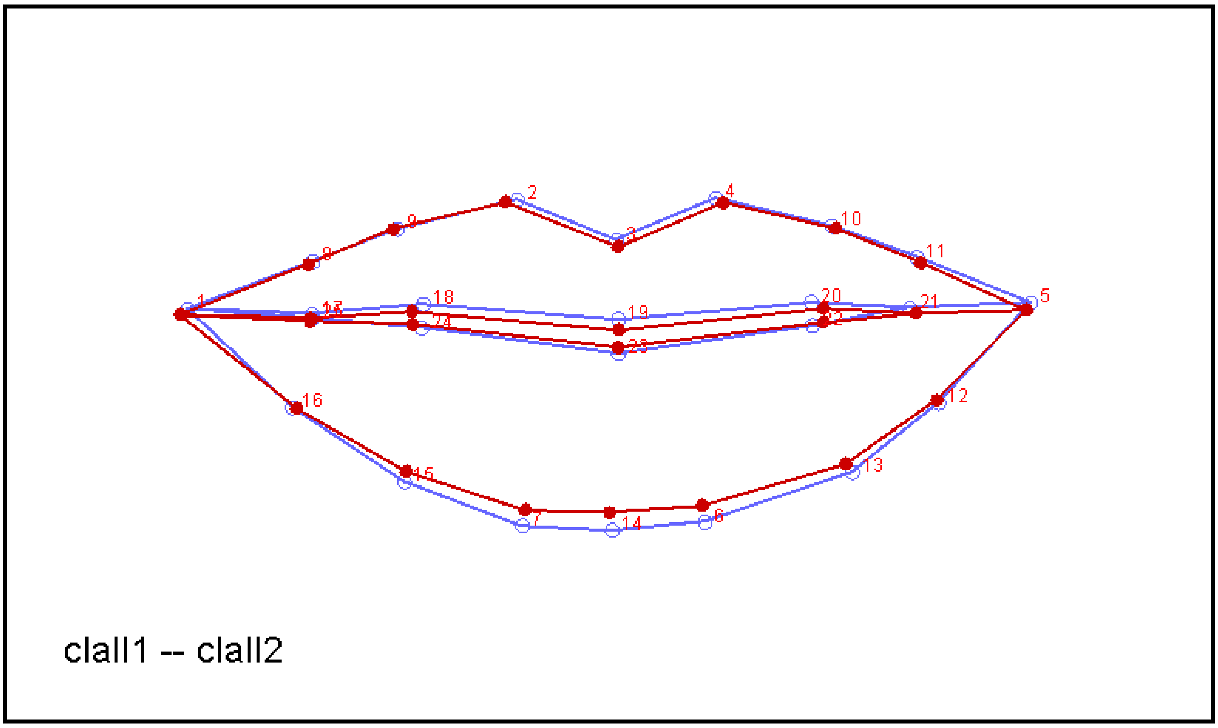


***Figure 4-13**: Superimposition of the lip outlines of class II div 1 (blue) and class II div 2 (red).*

The outline of class II div 1 comparing to class II div 2 showed an increased height of lower vermillion border (landmarks 6 & 7 and semilandmarks 12, 13, 14, 15) and lips slightly incompetent in class II div 1.

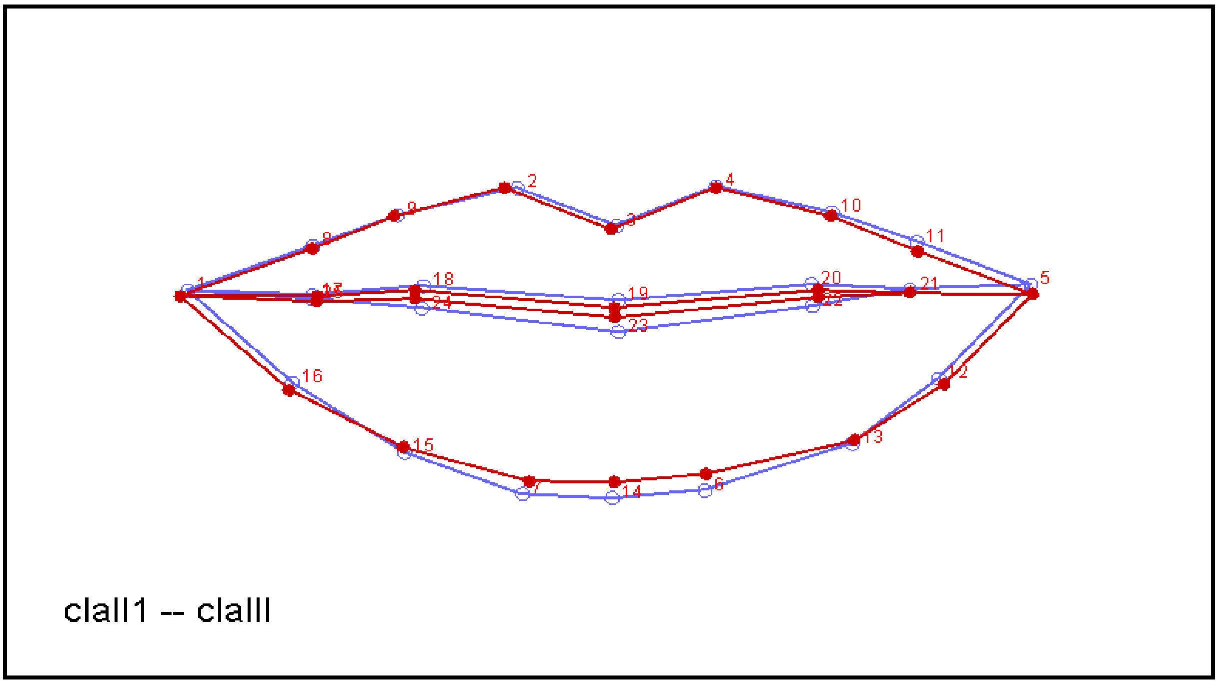


Figure 4-14: *Superimposition of the lip outlines of class II div 1 (blue) and class III (red).*

The increased height of lower vermillion border of class II div 1 outline especially in points (6, 14, and 7) did not indicate that lower vermillion height was bigger in class II div 1, but simply that class III subject had more competent lips.

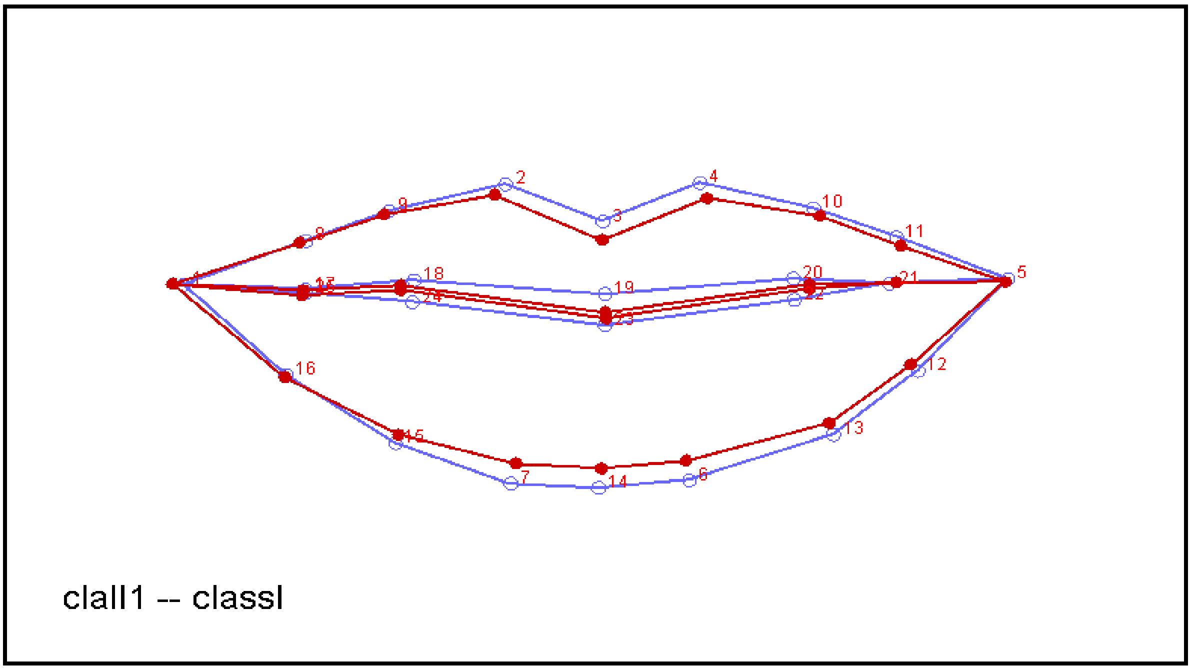


Figure 4-15: *Superimposition of the lip outlines of class II div 1 (blue) and class I (red).*

In Figure 4-15, the height of upper and lower vermillion borders of class II div 1 especially in points (2, 3,4,10, 12, 13, 6, 14, 7, and 15). Class I subject had more competent lips and this consistent with morphological analysis as class I subjects had higher percentage with thin lips.

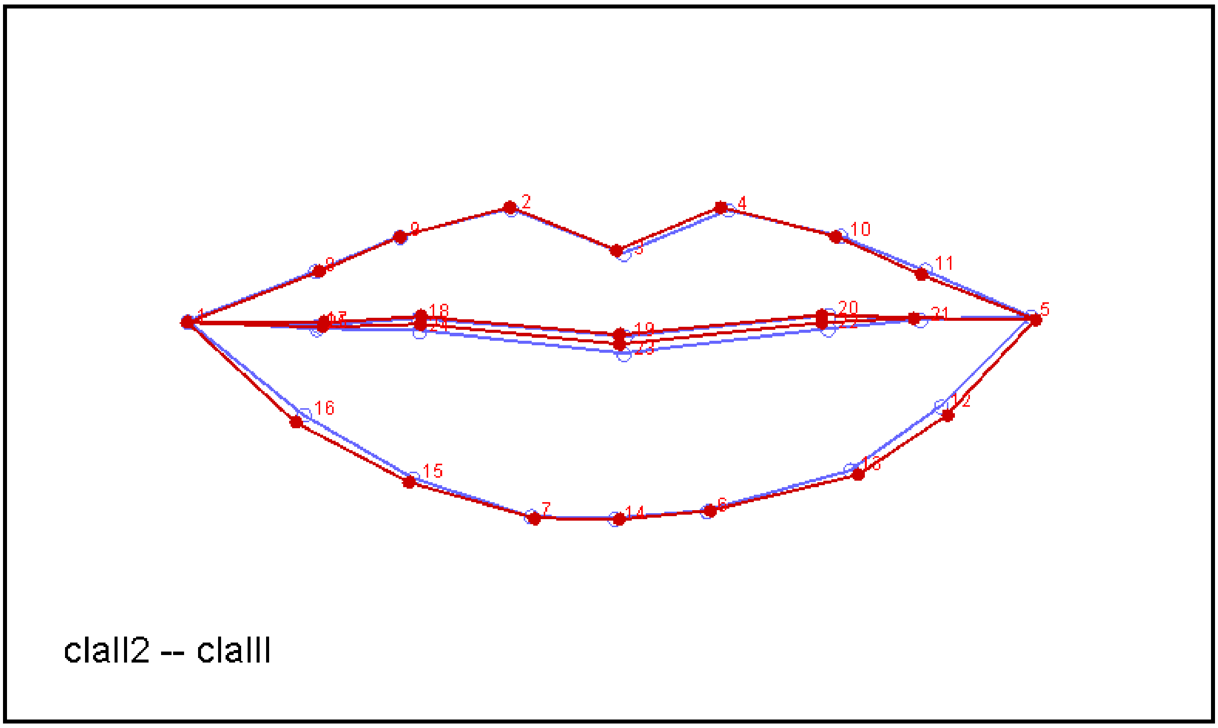


Figure 4-16: *Superimposition of the lip outlines of class II div 2 (blue) and class III (red).*

For class II div 2 in contrary of class II div 1 (see Figure 4-14) demonstrated more overlap with class III outline and showed more competent lips than class II div 1.

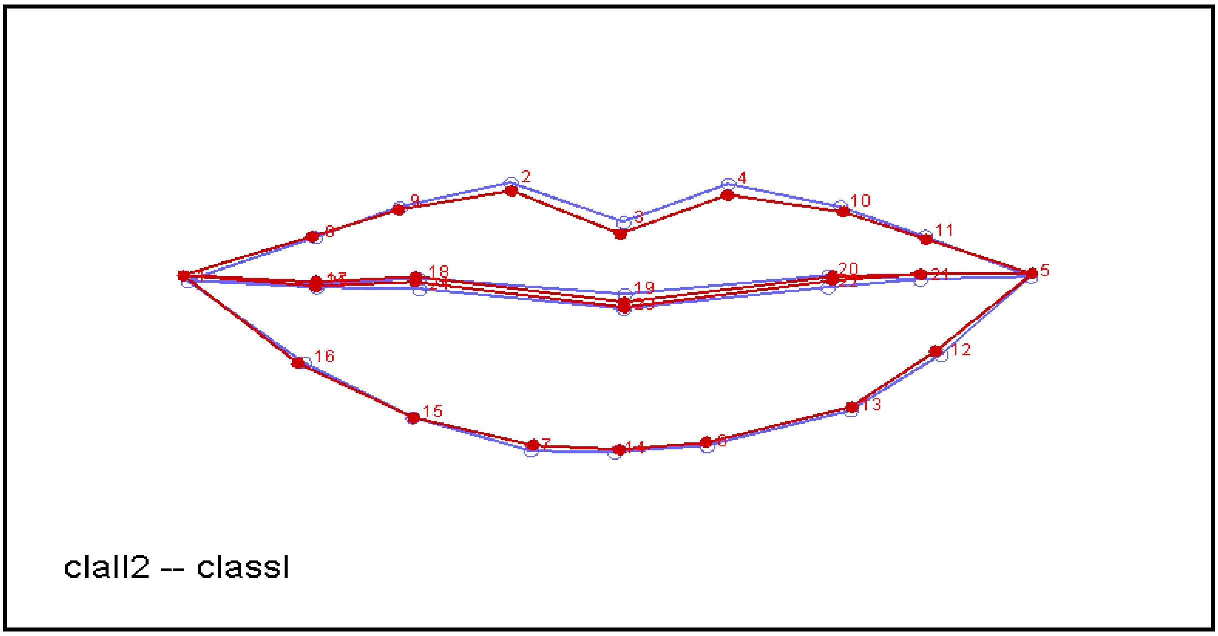


Figure 4-17: *Superimposition of the lip outlines of class II div 2 (blue) and class I (red).*

Class II div 2 outline showed more height especially in points (2, 3, and 4) which represent the cupid bow area than class I subjects which gave more height at the upper vermillion border.

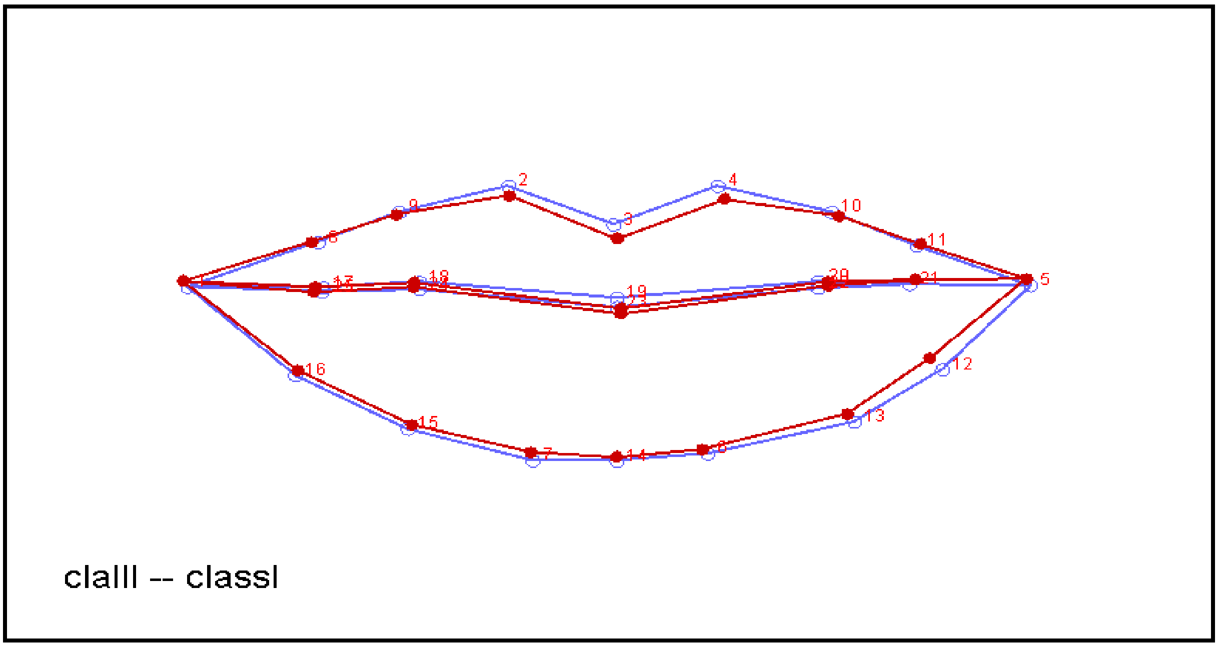


Figure 4-18: *Superimposition of the lip outlines of class III (blue) and class I (red).*

In class III outline superimposition with class I vermillion borders outlines showed more height in the upper vermillion border especially in cupid bow area and points (12, 13, 15, and 16).

4.5.2 Summary of GMM Findings

To summarise the GMM findings, the tangent space approximation (Table 4-4) for the all Scottish and Jordanian malocclusion classes was 0.99. When the result of a regression with both slope and correlation is almost equal to 1, the results of the approximation can be considered to be excellent; furthermore there were no obvious outliers identified in the initial screening for outliers in the malocclusion classes.

Procrustes ANOVA suggested a promising result as malocclusion classes explained 82% of vermilion border morphology differences. The results showed that the main effect of the malocclusion class was highly significant. The effect of sex and country of origin accounted for a negligible percentage difference and differences related predominantly to size rather than shape. The results of the superimposition also demonstrated that the range of vermilion border shapes overlapped differently in the malocclusion classes.

4.6 Association between Morphological Traits, GMM, and Cephalometric Variable

The separate results of cephalometric, morphological, and GMM analysis suggest that the antero-posterior and vertical dimensions and the upper and the lower incisor inclinations can predict many morphological traits of the soft tissue of the lips. Some cephalometric variables and some morphological traits had significant differences between malocclusion classes. However, to collectively assess and measure the association of these results in each malocclusion class to help prediction the nasolabial morphology a Spearman's rank-order correlation was run to assess the relationship between malocclusion class and these traits.

Regardless of malocclusion class, country of origin, and sex of subjects, there was a correlation between the following traits (Table 4-22):

Traits	rs	P-value	Comment
CM-Sn-Ls and Sts-Sn	-0.512	0.005	A moderate negative correlation between the nasolabial angle and the upper lip length.
CM-Sn-Ls and A-A’	0.388	0.041	A fair positive correlation between the nasolabial angle and upper lips thickness.
Pr-A’ and A-A’	0.637	< 0.001	A positive correlation between nose depth and upper lip distance
Philtrum shape and Sts-Sn	-0.881	0.010	There was a negative correlation between philtrum shape and upper lip length.
Upper lip fullness and A-A’	0.802	0.004	A strong correlation between upper lip fullness and upper lip thickness (A-A’).
Lower lip fullness and B-B’	0.798	0.007	A positive correlation between lower lip fullness and lower lip thickness (B-B’).

Spearman Rank-order Coefficient (*r*s)

Table 4-22: *Traits that displayed a correlation between each other regardless of malocclusion class, country of origin, and sex of subjects.*

Also there were significant correlations between malocclusion class and the following traits (Table 4-23):

Traits	rs	P-value	Comment
CM-Sn-Ls	0.235	0.013	A fair correlations between malocclusion class and the nasolabial angle.
Pr-A’	0.196	0.039	A fair correlations between malocclusion class and nose depth
Sti-Me’	0.389	< 0.001	A fair correlations between malocclusion class and lower lip length
Pog-Pog’	0.472	0.009	A fair correlations between malocclusion class and soft tissue chin
Upper vermillion border	0.796	< 0.001	A strong correlation
Lower vermillion border	0.716	< 0.001	A strong correlation

Spearman Rank-order Coefficient (*r*s)

Table 4-23: *Traits that displayed a correlation with subject’s malocclusion class.*

The flow chart 4-1 summarised the main characteristic traits in each malocclusion class.

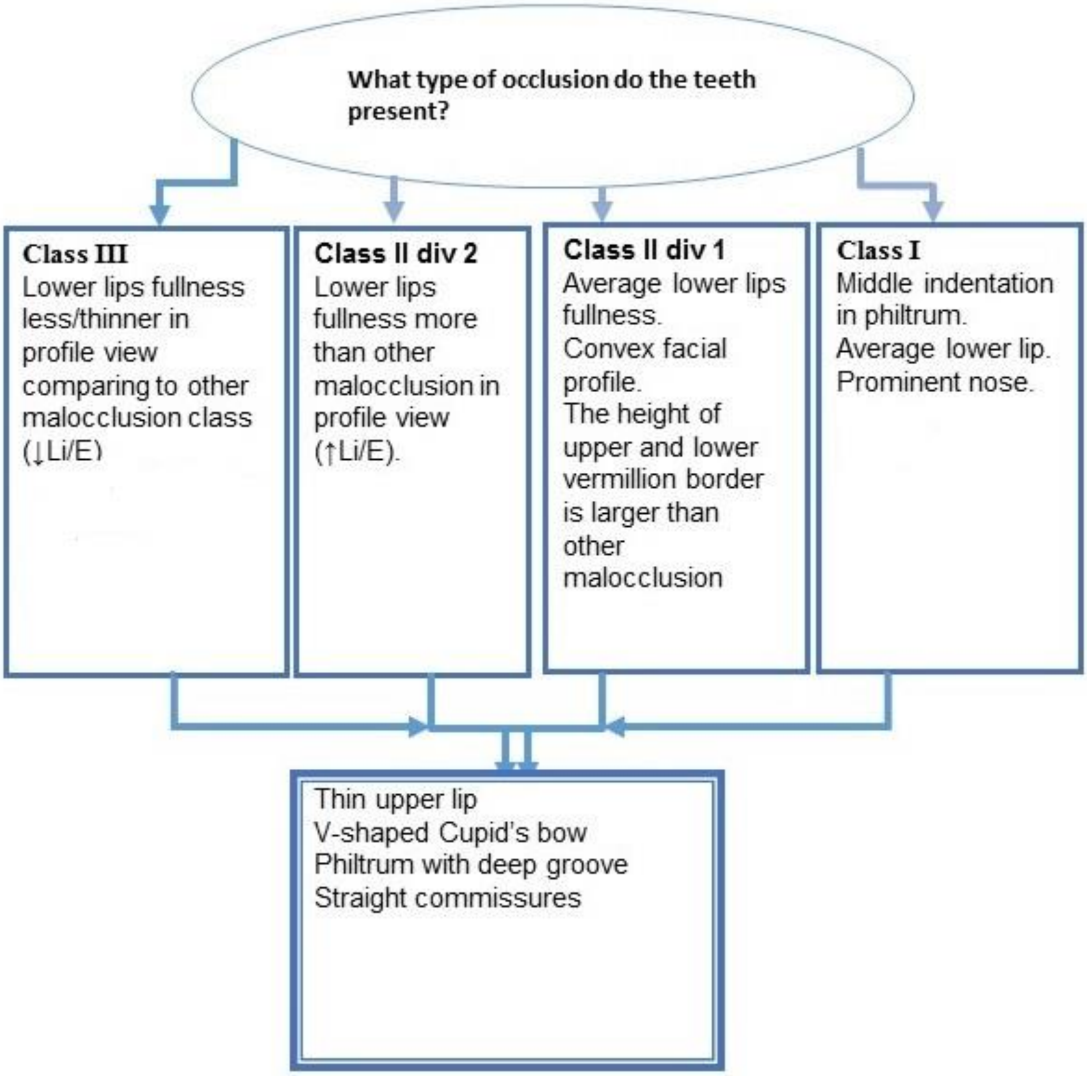


***Chart 4-1**: The distinguishing soft tissue morphological traits for each malocclusion class.*

Chart one summaries the characteristic soft tissue morphological traits for each malocclusion class. Some traits were the same across malocclusion classes, namely: V- shaped Cupid's bow, thin upper vermillion fullness except class II div 1 subjects, and straight commissures shape. However, other traits were characteristic to certain malocclusion class. The distribution of morphological traits showed no sex differences.

Chapter 5
Discussion

5.1 General Discussion

This study was conducted to explore and enumerate the correlations between different malocclusion types and vermillion border shape. Different analyses were carried out in order to describe the vermillion border outline and any correlation with the incisor relationship, and the focus of this study was the malocclusion class rather than any specific teeth measurements, as seen in previous studies (Wilkinson *et al*., 2003; Stephan, 2003; Stephan & Henneberg, 2003). The analysis focused on the vermillion border, as this feature has never been analysed in detail and is one of the more difficult features of the face to accurately predict (Wilkinson, 2010).

Many researchers have employed different measurements and methods to evaluate mouth width and vermillion border outlines from skeletal and dental pattern (Neger, 1959; Holdaway, 1983; Wilkinson *et al*., 2003, Tanikawa *et al*., 2009), and reconstruction approaches often rely on imaginative interpretation of mouth estimation (Prag & Neave, 1997) where the mouth is determined to be in harmony with other facial features such as the eyes and nose. A number of investigators (Gerasimov, 1955; Angel, 1978; Krogman & İşcan, 1986; Stephan & Henneberg, 2003; Wilkinson *et al.*, 2003) have established some of the principles that can be used to reconstruct the mouth using assessment of dental pattern and malocclusion; nevertheless, the precise shape of the vermilion line is challenging and hard to predict (Wilkinson *et al.*, 2006; Wilkinson, 2010; Short *et al.*, 2014). Wilkinson (2010) stated "*However, the exact shape of the vermillion line is difficult to predict with any degree of accuracy, as illustrated by the results of a metrical evaluation in which lip shape was found* *to be one of the most error-prone areas of reconstruction (Wilkinson et al. 2006). Successful forensic reconstructions have been demonstrated where the practitioner has modeled the lips ‘in sympathy’ with the rest of the face (Prag & Neave, 1997), although this may be more luck than judgment.*” (Wilkinson, 2010). It is true that these features are very subtle, however, the crucial aim of CFR is to re-build the in-vivo features of an individual to allow recognition (Prag & Neave, 1997; Wilkinson, 2010). Previous studies have been unsuccessful in conceiving a classification system for the vermillion borders and the commissures of lips. Therefore, it is important to update the principles that are already used to predict labial features from dental patterns and to establish whether malocclusion class is correlated with vermillion outline.

5.2 Facial Profile Assessment

5.2.1 Facial Profile Assessment using Cephalometric Analysis

The cephalometric analysis aimed to define the characteristic features of the malocclusion classes in order to enhance the facial reconstruction of facial profile and the vermillion border shape. In particular, the study focused on the soft tissue depth points: A-A’, B-B’, and Pog-Pog’.

Although different tracing methods were carried out for the cephalometric analysis of the Scottish (manual) and the Jordanian (digital) samples the intra- and inter-observer tests confirmed the methods were reliable and repeatable (Appendix III: Table III-1 to Table III-4). Therefore it can be assumed that the tracing method did not affect the comparison or the results.

The cephalogram measurements revealed that there were no significant differences between observers, demonstrating reliability and consistency across the results (Appendix III: Table III-1- Table III-4).

5.2.1.1Cephalometric Angles and Facial Height Measurements

The assessment of the facial profile using cephalometric analysis started by assessing the soft tissue convexity. The angle of total soft tissue convexity (N'-Pr-Pog'), demonstrated no statistically significant difference between the malocclusion classes. However, the angle of soft tissue convexity (N'-Sn-Pog') revealed smaller values in class II div 1 individuals, and the highest value was noticed in class III subjects. The values of (N'-Sn-Pog') showed no differences between males and females. Therefore, class III subjects had a less convex profile whilst class II div 1 had a more convex profile. This finding was consistent with the characteristic features of class III as the overjet in class III is reduced or demonstrated a reversed affect on the facial profile of the subject. Therefore, the average value of soft tissue convexity of each malocclusion class with age group studied (i.e. 11-14 years) was recommended to be added to CFR database.

The nasolabial convexity angle (Cm–Sn–Ls) showed no sex differences, but did differ between subjects according to their country of origin with class III subjects showing smaller values than the other three malocclusion classes.

The changes in nasolabial angle among malocclusion classes and the two populations were difficult to explain. Fitzgerald *et al.* (1992) stated that "*since this angle is formed by two lines, one from the nose and the other from the upper lip, and both independent of each other, the measurement of this angle alone does not reveal which component is responsible for the variability. It could be the nose, the lip or both.*" (Fitzgerald *et al.*, 1992).

Further analysis showed that there was a positive correlation was seen between the nasolabial angle and A-A', which measures the upper lip thickness in the anterior-posterior plane. Since the correlation between nasolabial angle and A-A' was positive this implied that the lip component, in this study, was more important in determining, and consequently explaining the differences in the nasolabial angle. Therefore, the cephalometric angles and linear measurements values should be considered together when reconstructing the nose and facial profile.

Important cephalometric measurements related to incisors' angulations were: UI/MX, LI/MP, and UI/LI. The present study showed significant differences between the two studied populations for the upper incisor axis to maxillary plane angle (UI/MX), and lower incisor axis to mandibular plane angle (LI/MP). However, the results revealed that there were no significant differences between the two populations in the inter-incisal angle (UI/LI). In addition all these measurements showed no sexual dimorphism, and this was in agreement with previous results for other ethnic groups: Americans (Gianelly, 1970), Chinese (Chan, 1972), southern Chinese and British Caucasians (Cooke & Wei, 1988). The upper incisor axis to maxillary plane angle (UI/MX) was higher in class II div1 subjects where as class II div 2 showed the lowest value. The inter-incisal angle was highest in the Scottish class II div 2 and the lowest value in class II div 1, reflecting the highest protrusion of anterior teeth in class II div 1 subjects, and consequently a convex facial profile. In the Jordanian subjects, the inter-incisal angle value was higher in class II div 2 and lowest in class II div 1 subjects; this angle indicates the relationship between the upper and lower anterior teeth and might reflect the facial profile of these subjects. Consequently, the assessment of the inter-incisal angle is recommended in advance of starting facial reconstruction, as it affects the facial profile between different malocclusion classes.

Regarding the facial height measurements, the results of the current study suggested that males and females had different upper facial measurements based on their malocclusion class. A study by de Freitas et al. (2007) reported that white Brazilian subjects, mean age 13.71 ± 0.84 years, had larger UAFH, with males having greater measurements than females. However, this study utilised subjects with normal occlusion and different ethnic groups. . Despite this, the study implied that the UAFH exhibited sexual dimorphism at this age group.

In contrast a previous adult study (Lefevre et al., 2012) reported that there was no evidence of sexual dimorphism in facial height measurement.

The results of lower facial height, were similar between the two studied populations regardless of their malocclusion class. The lower facial height measurements showed no differences between males and females. These findings contradict a recent study (Tanikawa *et al.*, 2015), which claimed that females had a shorter lower facial height compared to males, and other study (Anić-Milosević *et al.*, 2009), which claimed that females tend to have smaller faces. However both previous studies analysed an older age group, above 18 years, rather than the younger age group in this study. To sum up, lower facial height measurements showed no differences between the populations or between the two sexes in the studied age group.

5.2.1.2 Cephalometric Linear Measurements

Cephalograms were used to measure the lip thickness (width in anterior-posterior plane) in the upper and lower lip using cephalometric landmarks. In the present study the upper and lower lip thicknesses (A-A' and B-B' respectively) were smaller in females than males. These results were consistent with other studies concerned with sexual dimorphism (Wilkinson, 2002; Rosas & Bastir 2002, Tanikawa *et al.*, 2015) where females had thinner lips than males regardless of age. These outcomes may because tissue depth in these areas were less in females than males, which was in agreement with a previous study by Wilkinson (2002) utilising White British children aged between 11 and 18 years, where the males showed larger tissue depths in the mid-philtral, upper lip border and lower lip border points. It was also was noticeable that the alveolar bone concavity in upper and lower jaws were straighter (Figure 5-1) in the studied samples which might explain the increased tissue depth in these area and consequently thicker lips in males. These findings were in agreement with Valenzano *et al.* (2006) which reported that females had more protruded alveolar bone than males. Also the finding is consistent with recent studies (Utsuno *et al.*, 2014; Pithon *et al*., 2013; Kamak & Celikoglu, 2012) who measured the soft tissue thickness in different malocclusion classes in the two sexes from different countries and all these studies confirmed that males have thicker soft tissue in the area of lips than females. This increase in tissue depth and differences in the shape of alveolar bone between the sexes leading to fuller lips in males than females which are difficult to explain in the studied samples due to the subjects ages where secondary sexual characteristics may not yet have developed fully.

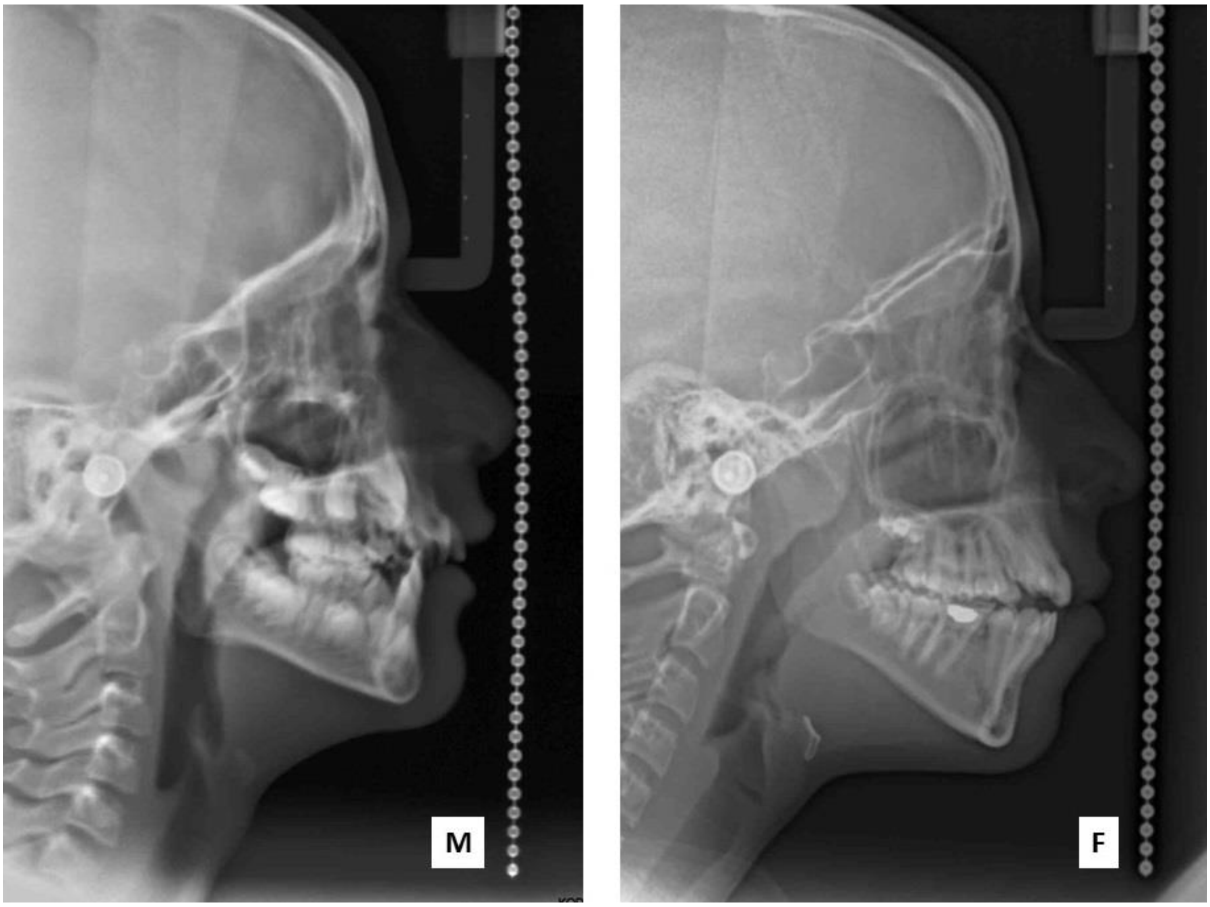


***Figure 5-1**: the differences of alveolar bone inclination between males (M) and females (F).*
Source: Jordanian Data/ Jordan University Hospital.

The nose depth (Pr-A') was similar between the sexes, but was higher in the Scottish than Jordanian subjects. This finding was in agreement with the nasolabial angle measurement, which was higher in the Scottish population than the Jordanian, which indicated the Scottish group had more a prominent nose than the Jordanian group. The highest nose depth value was recorded in class I subjects and the lowest value recorded in class III subjects. This finding reinforced the result that class III subjects had a less convex profile and less lower lip thickness, moreover, from the orthodontic point of view and the soft tissue thickness measurements in different malocclusion classes (Utsuno *et al.*, 2014; Pithon *et al.*, 2013; Kamak & Celikoglu, 2012).

5.2.1 Facial Profile Assessment using Morphological Analysis

Morphological analysis using profile-view photographs was employed to assess two traits: the upper and the lower vermillion border fullness. For morphological traits analysis, the intra-observer and inter-observer tests (Table 4-1 & Table 4-2) demonstrated consistency across all traits measured.. The term “Lip fullness” was used to assess the amount of pigmented area of anatomical lips using the profile view photograph Figure (5-2).

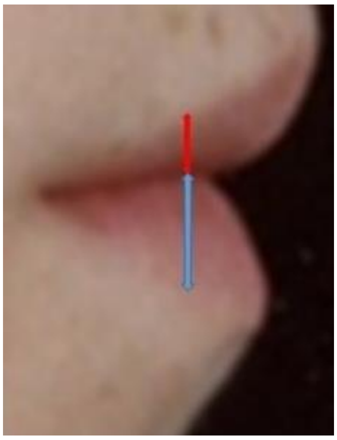


***Figure 5-2**: The profile photograph of the participant, red and blue arrows show the upper and lower vermillion area used to assess the fullness of the lips.*

Source: Jordanian Data/ Jordan University Hospital.

Studies that describe lip fullness (Gerasimov, 1971; Gatliff & Snow, 1979; Wilkinson *et al.*, 2003) suggest that there is a correlation between maxillary anterior teeth height and upper lip vermillion height, and also mandibular anterior teeth height and lower vermillion height. It was difficult to confirm these findings or correlations in the present study because the dental casts of the Jordanian participants were unavailable. In Ritz-Timme *et al.* (2011), they used three terms to assess lip fullness: narrow, average, and broad. In this study, lip fullness was assessed for the upper vermillion border and lower vermillion border in profile view separately, and for each the term lip fullness was subdivided into three categories: thin, thick and average following a similar approach to Wilson *et al.* (2012).

This study revealed significant differences between different countries of origin, and Jordanian class III subjects were associated with average lips, while other classes were associated with thin lips. Similarly, thin upper lip fullness was a characteristic feature of Scottish subjects. As Scottish people are white Europeans and Jordanians are Middle Eastern/Asian these results disagree with Wilkinson *et al.*, who suggested that white Europeans have thinner lips than Asians (Wilkinson *et al.*, 2003). Ritz-Timme *et al.* (2011) claimed that European males from Germany, Italy, and Lithuania (77%, 83%, and 67% respectively) had average lip thickness; however, these findings contradict this study where there was no sexual dimorphism pertaining to lip fullness. Many studies (Farkas *et al.*, 1992; Ferrario *et al.*, 2005; (Utsuno *et al.*, 2014; Pithon *et al*., 2013; Kamak & Celikoglu, 2012) claimed that oral measurements, mouth width, lip height, and soft tissue lip thickness were lower in females, which was supported by the cephalometric and GMM results of the present study, but not with the results of the morphological study. This might be explained by the subjective nature of morphological assessment using photographs, and therefore the cephalometric (specially upper and lower lips thickness (A-A’ and B-B’)) and GMM measurements might produce more reliable results. However, the findings here contradict Medlej (2014), who claimed that men generally have thinner and less fleshy lips than women, as both the Scottish and Jordanian samples showed no significant difference at the upper lip and lower lip fullness between males and females.

5.3 Lip Thickness and Morphological traits

Previous work by Wilson *et al.* (2012) showed that certain features were associated with each other, and the present study supported this: in the Jordanian sample associations were observed between the average upper lip fullness and the deep groove philtrum shape, V-shaped cupid bow and thin upper lip, and the association between thin upper lip with thin lower lips and an average upper lip with an average lower lip, while, in the Scottish sample, individuals with thin upper lips tended to have thin lower lips.

In summary, the two populations generally had thin upper lip vermillion borders in all malocclusion classes with males having larger lip height especially in the Cupid's bow area rather than the mouth width area. The nose was more prominent in class I subjects and in the Scottish population.

5.4 Prediction of Lower Vermillion Border and Lip Fullness

The lower lip linear measurements showed that the Jordanian sample had thicker lower lips and thicker soft tissue chin, especially in class II div 1, than the Scottish sample regardless of their malocclusion class. This result might be related to differences between the ethnic groups despite having a similar ancestry.. These findings demonstraed differences in lower lip length between the two divisions of class II malocclusions, which might be explained by differences in anterior teeth inclinations. Div 1 had thinner and less full lips than Div 2, indicating the necessity to assess the malocclusion class carefully before a facial reconstruction is undertaken.

The morphological analysis showed that lower lip fullness was not different between malocclusion classes. However, as stated earlier, the height of the vermilion border outline, which corresponded to lip fullness, was found to be significantly correlated to malocclusion class; with the largest for class II div 1, followed by those for class III, class II div 2, and class I. This observation was linked to the differences of the anterior teeth inclination in different malocclusion classes. Also this outcome might be explained by class II div 1 which is characterised by an increased overjet and protruding maxillary central incisors leading to incompetent lips as a general feature. This might then lead to soft tissue adaption and thicker lips in class II div 1 subjects compared to other malocclusion classes. Unfortunately, there are no previous studies to compare these finding with.

The height of the vermilion border differed between the sexes explaining less than 3% of vermillion border differences, where the males had slightly larger sizes than the females, which is in agreement with several previous studies (Farkas *et al*., 1992; Wilkinson, 2002; Ferrario *et al*., 2005)

5.5 Philtrum Shape and Cupid's bow Shape

Other important traits analysed in this study were the philtrum shape and the Cupid's bow shape, which were assessed from frontal view photographs. These traits were also examined in previous studies (İşcan & Helmer, 1993; Mori *et al*., 2005; Ritz-Timme *et al*., 2011; Wilson *et al*., 2012). In the present study the morphological analysis followed a similar approach to Wilson *et al.* (2012); however, many variables were excluded, firstly, because of the relatively small sample size comparing to the Wilson *et al*. (2012) sample size of 2,240 children. Secondly, Wilson *et al.* (2012) converted scanned images into facial shells using a reverse engineering package able to recognise surface contours, while the material in this study was two-dimensional and as such, did not permit many details to be assessed. For example, it was very difficult to test the philtrum width and it was difficult to notice the small indentations as some patients appeared to have when looking at their three quarter view photographs; even though these patients appeared to have a smooth philtrum shape in frontal view photographs.

There were no significant associations between the two studied populations and the two sexes however the pooled results showed that class I subjects were more likely to have a philtrum shape characterised with middle indentation and class III subjects were more likely to have a deep groove at the columella extending through the vermillion border.

This differs from Ritz-Timme *et al.* (2011), who found average philtrum height, a philtrum with shallow and divergent sides, and a wavy upper lip notch indicated that Caucasians mostly have a V-shaped cupid bow regardless of their malocclusion or ethnic groups. However the present results are similar to those of Wilson *et al.* (2012), where the V-shaped cupid bow was more associated with a deep philtrum groove (60.3%) than a smooth philtrum (7.4%).

According to Carey *et al.* (2009) and Wilson *et al.* (2012), a flat cupid bow was accompanied by a smooth philtral shape. The results of the present study support the link between the philtral shape, Cupid's bow and other morphological traits average upper lip fullness and deep groove philtrum shape, and V-shaped cupid bow and thin upper lip.

5.6 Commissures

Commissure shape is an important feature in lips, and has been investigated in previous research. Ritz-Timme *et al.* (2011) described commissures as "*the orientation of mouth corners*" and had three classes: slightly up, straight, and slightly down, which are analogous to this study. Wilson *et al.* (2012) classed mouth angles as: upturned, straight, and downturned, which is very similar to this study. The results showed that majority of the data had straight commissures regardless of their malocclusion class or sex, or country of origin. Ritz-Timme *et al.* (2011), had similar results for commissure shapes, as most participants had straight commissures, but this study contradicts the study by Wilson *et al*. (2012), where the downturned commissure shape was the most frequent finding (50.6%). In the present study, there was a significant association between straight commissure (63.2%) and a deep groove philtrum shape.

Mouth width was not measured in this study as the assessment of mouth width using the 2D photographs (see Figure 1-3) was not possible because not all subjects had frontal view photographs showing their teeth.

5.7 Summary

There is a great deal of variation in vermillion border morphology and the morphological analysis recognised a diversity of naso-labial morphological features that can be classified. The results demonstrate a high level of intra-observer reliability, as well as high inter-observer reliability across both the Scottish and Jordanian data sets.

Differentiation and classification of the vermillion borders using cephalometric measurements and geometric morphometric analysis should continue to be studied using larger samples and multiple ethnic groups to achieve a classification system of the vermillion border for each malocclusion class. GMM and cephalometric results demonstrated that vermillion border variation can be measured and analysis and investigation of vermillion borders using geometric morphometric methods along with informative prior data such as sex or demographic information should be subjected to further research using larger samples and multiple ethnic groups to achieve a consistent classification system of the vermillion border for each malocclusion class, which could produce a much more accurate assessment of unidentified human remains.

Chapter 6
Conclusion

6.1 Conclusion

The central aim of the study was to establish the relationship between dental occlusion by investigating four malocclusion classes and lip morphology. The results revealed that some lip traits were associated with different malocclusion classes. Due to their shared ancestry (Caucasian), both Jordanian and Scottish populations showed the same morphological trends for the lips, for example: a deep philtrum, V-shaped cupid bow, a thin upper vermillion border, and straight commissures' shape. Morphological analysis also recognised a diversity of naso-labial morphological features that were not easy to classify.

As all the naso-labial morphological traits were subjectively analysed, and no measurements performed, it was difficult to quantify and locate a threshold where a certain trait should end; for example, to allow a judgment of whether fullness of lips should be classified as thin, average or thick. Despite these concerns, the results of the intra-observer and inter-observer reliability tests (Table 4-1 & Table 4-2) in the Scottish and Jordanian data suggested that this lip fullness classification was reliable and reproducible.

In this study, several of the morphological features could be associated with certain malocclusion classes. Specifically, nasolabial angle, nose depth, and lower lip length, and soft tissue chin, upper and lower vermillion border fullness. The outcomes from the collective analyses described, can be used to make a prediction about the morphology of naso-labial features, using the skull and assessing the type of malocclusion.

Employing the Geometric Morphometric (GMM) analysis seems to provide promising results. GMM results suggested that vermillion border variation could be computed and quantified, at least when distinguishing between malocclusion classes from the same ethnic group. GMM revealed that the shape and diversity in the vermillion border outline mainly revealed differences between malocclusion classes (Table 4-19).

This research recorded association between some vermillion border morphological traits and cephalogram variables to certain malocclusion classes; however, further investigation is necessary to confirm the results, particularly, with the lack of previous studies within the same scope.

Cephalometric analysis which assessed the facial convexity, facial height, upper and lower lips measurements showed that these findings indicated that the malocclusion assessment was more important than country of origin as the cephalometric measurements within the malocclusion classes were very similar between the two populations, and differences between the sexes were minimal.

6.2 Implications for further research and study

This study showed that using photographs for morphological assessment and geometric morphometric methods along with cephalogram measurements was a useful method for analysing faces. Further research is essential to evaluate whether the methods employed and the results achieved in this study can be (a) replicated in other studies and (b) scientifically and clinically significant.

Although the outcomes of this study were promising, further study is needed prior to any definitive statements about the effectiveness of the GMM method and cephalometric analysis as a tool for determining naso-labial morphology. It is recommended that a larger sample size is collected to allow statistically powered analyses even when sub-dividing according to sex, malocclusion type, country of origin, and age group. Future research should encompass different ancestry groups, so findings can be compared to improve classification, reconstruction, and identification of naso-labial morphology. Other sets of landmark configurations should also be explored in greater detail to determine where most of the occlusion-related variation occurs.

As more cephalograms become digitalised, analysis and visualisation software is improved, and angles and linear dimensions on digital cephalograms computed, classification accuracy should improve as minor differences become detectable.

Any extension of this research should strive to develop a successful protocol for naso-labial morphology classification, by assessing teeth pattern. The results achieved in this study can be compared with data already used in mouth and vermillion border reconstruction. GMM may also be applied to cephalogram analysis for facial identification and orthodontic assessment. This could provide quantitative shape information to support and corroborate approaches already in use.

The first sets of standards of angular, linear cephalograms measurements, and sequence of subjectively assessed traits specific to the Jordanian and Scottish populations in different malocclusion classes, were provided and found to be consistent with each other, as both are considered to be one of the Caucasian populations. These standards hope to aid prediction of vermillion border outlines.

It is recommended that forensic facial scientists, anthropologists, and orthodontists should standardise the terminology used in facial description, especially those related to lips, malocclusions, and descriptions of dental morphology.

Any study in forensic facial reconstruction definitely adds to this science and helps the researchers to build a scientific database to increase the reliability of moulding the face. It also decreases the dependence on the subjective judgement and artistic ability of the artist/scientist producing the facial reconstruction.

6.3 Summary conclusions

This study has shown for the first time that there are similarities in the nasolabial soft tissue morphology between populations and a more significant difference related to malocclusion type. This study also showed that differences between the sexes and ethnic groups were minimal. The characterisation of these similarities and differences will assist in future forensic reconstruction. The key findings are as follows:

1. Cephalometric measurements and GMM can be used to distinguish different types of malocclusion. As class II subjects had fuller lips than class III and class I.

2. Some nasolabial traits are associated with the type of malocclusion particularly lip fullness and philtrum shapes.

3. Nasolabial soft tissue differences between the two sexes were minimal, where males had fuller lips than females, while other features such as the shape of the cupid bow and the commissures showed no sex dimorphism.

4. Lip fullness classification was found to be reliable and reproducible as shown by intra- and inter-reliability (Appendix III: Table III-5 & Table III-6).

5. Some vermillion morphological traits and cephalometric measurements correlate with different types of malocclusion, and with each other (explained in chapter four).

6.4 Strengths and Limitations

This research is the first to compare the naso-labial features of these two populations: Scottish and Jordanian, and the results demonstrated that the two ethnic groups were very similar. Moreover, this is the first study to combine photographic analysis using GMM with a cephalometric analysis, and this produced statistically significant results.

There were several limitations that complicated this study, which may have had some impact on the results. The majority of the limitations concern the sample size analysed. All the data were selected from the archive of the Dental Hospital at the University of Dundee and from the Orthodontic department at Jordan University Hospital. Although both departments follow a similar and universal protocol when taking photographs and cephalograms, not all the data were of the same quality. For example, the first frontal view of the subject must be in a neutral facial expression. However, some photographs showed patients who were smiling and consequently these photographs and those not complying with the protocol had to be excluded, which negatively affected the sample size. Also the majority of Jordanian data were of age group 11-14 years and accordingly, in order to have a balanced experimental design many cases had to be excluded from the Scottish sample. This age group is critical as this is when there is an acknowledged growth spurt due to puberty and experts estimate this to start at age 11 in girls and at age 13 in boys. Whilst it is true that lip shape might change after this age period, this study has produced some standards linking lip morphology to malocclusion class. At present there are very few studies relevant to juvenile subjects which include white British data (Wilkinson, 2002), US juvenile study (Manhein et al., 2000) and Japanese juvenile study (Utsuno et al., 2010) and, therefore, the linear and cephalometric measurements could be an additional input to the current database.

To summarise, the strengths of this study are as follows:

- These are the first published lip morphology prediction standards that can be employed for subjects with malocclusion types.
- There are consistent nasolabial morphological differences between different malocclusion types within the two populations studied.
- The variation between malocclusion types is greater than that between population groups, but bearing in mind both populations studied here were of Caucasian origin.
- The variation in nasolabial soft tissue morphology between males and females within malocclusion classes is minimal, particularly in terms of shape, but as expected there is a tendency toward male-female size difference.
- The geometric morphometric analyses suggest that vermillion border variation can be computed.
- These standards may enable more accurate facial depiction from skeletal remains in forensic identification and archaeological investigation.

But the study also has limitations, which call for future investigation:

- The results are representative of a specific age group only, and it is uncertain whether they can be applied to an adult population.
- The results are representative of malocclusion classes only, and it is uncertain whether they can be applied to subjects with normal occlusion.
- The results are representative of specific ethnic groups, and it is uncertain whether they can be applied to a wider population or different ethnic groups.
- The results suggest certain relationships between dental pattern and lip morphology, but do not enable the exact prediction of lip shape at an individual level.
- Some aspects of lip morphology prediction will be subjective and may therefore be somewhat unreliable.

Appendices

Appendix I

Ethical Approval/Jordanian sample

Jordan University Hospital

مستشفى الجامعة الأردنية
Jordan University Hospital

A-ADM0112

الرقم: ٨٤/٢٠١٢/IRB
Ref.

التاريخ: ٢٠١٢/١١/١١
Date:

الأستاذ الدكتور رئيس لجنة البحث العلمي

تحية طيبة و بعد،،،،

اشارة إلى مشروحاتكم على حاشية كتاب مديرة دائرة طب الأسنان رقم 1024/4/8 تاريخ 2013/8/1 بخصوص بحث الطبيبة **أمل البطوش** و بالتعاون مع الدكتور **أحمد محمد حمدان** و الذي بعنوان:

"Prediction of nasolabial morphology from dental pattern assessment"

و حيث أن البحث المذكور لا يستدعي إستخدام أدوية جديدة لغايات الدراسة أو تعديل أدوية موجودة، حيث يدخل البحث ضمن المعايير السريرية الثابتة للعناية الطبية و المتمثلة بالتعاون مع الأستاذ الدكتور أحمد محمد حمدان لعمل بعض القياسات/دراسات على بعض مرضى التقويم في عيادته في مستشفى الجامعة الأردنية.

و حيث أن الطريقة التي ستقومون بإستخدامها هي طريقة مستخدمة ضمن العناية الروتينية. لذا فإن اللجنة المؤسسية للدراسات الدوائية (IRB) توصي بالموافقة على اجراء هذا البحث شريطة الحصول على إقرار موافقة المريض المعد لهذه الغاية شريطة ما يلي:-

- عمل نسخة باللغة العربية للموافقة المستنيرة مع إضافة الجملة التالية:-

(و ان هذه الموافقة مشروطة بالبحث المبين و لا يجوز إستخدام العينات لأي بحث أو دراسة أخرى دون أخذ موافقتي)

- انه يحق للجنة الأخلاقيات طلب إقرار الموافقات المستنيرة من الباحثين في أي وقت و الاطلاع عليها و كذلك يجب الإحتفاظ بها في ملف الدراسة لمدة عامين من تاريخ الموافقة عليها من قبل اللجنة.

مع الشكر و التحية،،،

رئيس اللجنة المؤسسية للدراسات الدوائية (IRB)

الأستاذ الدكتور عبدالله العبـــــادي عويدي

تلفون ٥٣٥٣٤٤٤ - فاكس ٥٣٥٣٣٨٨ - صندوق بريد ١٣٠٤٦ - عمان - الأردن
Tel. 5353444 Fax 5353388 - P.O.Box 13046 - Amman - Jordan

Jordan University Hospital

مستشفى الجامعة الأردنيــة

Ref.

Date:

الرقـم : ١٤٩٧٩/٢٠١٣/١٠

التاريخ : ٢٠١٣/١١/١٩

الأستاذ الدكتور مدير عام مستشفى الجامعة الأردنيــة

تحية طيبة وبعــد ،،

ناقشت لجنة البحث العلمي في جلستها رقم (٢٠١٣/٤) بتاريخ ٢٠١٣/١١/١٤ بحث الدكتورة أمل البطوش بعنوان :

" Prediction of nasolabial morphology from dental pattern assessment"

وبعد المداولة توصي اللجنة بما يلي :

القرار رقم ٢٠١٣/٦١:

توصي اللجنة بالموافقة على إجراء البحث المذكور أعلاه، شريطة ذكر مستشفى الجامعة الأردنية بالبحث والتوقيع على إقرار التعهد الباحث.

مــع التحيــة،،،

رئيــس لجنــة البحــث العلمــي

الأستـــاذ الدكتـــور إسـلام مسـاد

نسخة إلى:

- أمين سر لجنة البحث العلمي.

The translation of the Jordanian ethical approval

Ref: IRB L/2013/84

Date: 11/11/2013

Dear Prof., Head of the Scientific Research Committee

Greetings,

In reference to your descriptions on the margin of the letter sent by the Manager of Dental Department No. 08/04/1024 dated August 1st, 2013 concerning the research made by Dentist Amal Albtoosh, in cooperation with Dr. Ahmed Mohammed Hamdan, under the title of: "Prediction of Nasolabial Morphology from Dental Pattern Assessment";

Whereas the said research does not require using new medicines for the purpose of study or modification to existing medicines, as the research falls under the category of the fixed clinical standards for medical care, represented through cooperation with Prof. Ahmed Mohammed Hamdan to make some measures/studies on some patients of orthodontics in his clinic in the Jordan University Hospital;

Whereas the method you are going to use is a method that is already being used in the care routine, therefore, the Institute for Research in Biomedicine (IRB) recommends approving conducting its research provided that the approval of the patient shall be obtained for this purpose, on condition of:

- Making a copy in Arabic Language for clear approval, including the addition of the following sentence:

  (And such approval is conditioned on the said research. Samples shall not be used for any other research or study without obtaining my approval)

- The Ethics Committee shall have the right to request and review the clear approvals from the researchers at any time. Furthermore, it shall be kept in the study profile for 2 years as of the date of approving such from the committee.

Sincerely Yours,
Head of IRB
Signed
Prof. Abdullah Al-Abbady Oiady

Jordan University Hospital

Ref: 10/2013/14979
Date: 19/11/2013
Dear Prof., general Manager of the Jordan University Hospital,
Greetings,
The Scientific Research Committee has discussed, in its session No. (4/2013) on 14/11/2013, the research submitted by Dr. Amal Albtoosh under the title of:
"Prediction of Nasolabial Morphology from Dental Pattern Assessment";
After negotiations, the committee shall recommend the following:
Resolution No. 61/2013:
The committee approves conducting the above mentioned research, provided that the Jordan University Hospital shall be mentioned in the research and that the researcher shall sign the declaration.

Sincerely Yours;

Head of the Scientific Research Committee
Prof. Islam Massad
Signed
To be arranged with Dr. Ziad Al-Baitar

A copy to:
- *The secretariat of the Scientific Research Committee*

The executive committee

Signed

Ethical Approval/Scottish sample

NHS SCOTLAND

East of Scotland Research Ethics Service (*EoSRES*) **Research Ethics Service**

TAyside medical Science Centre
Residency Block Level 3
George Pirie Way
Ninewells Hospital and Medical School
Dundee DD1 9SY

Professor Peter A Mossey
School of Dentistry
University of Dundee
Park Place, Nethergate
Dundee
DD14HR

Date:	21 December 2015
Your Ref:	
Our Ref:	LR/**15/ES/0186**
Enquiries to:	Mrs Lorraine Reilly
Direct Line:	01382 383878
Email:	eosres.tayside@nhs.net

Dear Professor Mossey

Title of the Database:	**Craniofacial Database**
REC reference:	**15/ES/0186**
IRAS project ID:	**188096**

Thank you for your letter of 17 December 2015, responding to the Committee's request for further information on the above research database and submitting revised documentation.

The further information was considered at the meeting of the Sub-Committee of the REC held on 21 December 2015. A list of the members who were present at the meeting is attached.

We plan to publish your research summary wording for the above study on the HRA website, together with your contact details. Publication will be no earlier than three months from the date of this favourable opinion letter. The expectation is that this information will be published for all studies that receive an ethical opinion but should you wish to provide a substitute contact point, wish to make a request to defer, or require further information, please contact the REC manager, Mrs Lorraine Reilly, eosres.tayside@nhs.net. Under very limited circumstances (e.g. for student research which has received an unfavourable opinion), it may be possible to grant an exemption to the publication of the study

Confirmation of ethical opinion

On behalf of the Committee, I am pleased to confirm a favourable ethical opinion of the above research database on the basis described in the application form and supporting documentation as revised.

Duration of ethical opinion

The favourable opinion is given for a period of five years from the date of this letter and provided that you comply with the standard conditions of ethical approval for Research Databases set out in the attached document. You are advised to study the conditions carefully. The opinion may be renewed for a further period of up to five years on receipt of a fresh application. It is suggested that the fresh application is made 3-6 months before the 5 years expires, to ensure continuous approval for the research database.

Approved documents

The documents reviewed and approved at the meeting were:

Document	Version	Date
IRAS Checklist XML [Checklist_17122015]		17 December 2015
Other [Remote poster]		
Other [Presentation - Omer Telli]		
Other [Remote Poster]	1	17 December 2015
Other [Letter of response]	1	17 December 2015
Other [SOP CFD]	1	17 December 2015
Other [CV - Data Controller]		17 December 2015
Participant consent form [Clinical Photograghy Consent Form - NHS Tayside]	2	17 December 2015
Participant information sheet (PIS)	1	17 December 2015
Protocol for management of the database [CFD Protocol]	1	12 October 2015
REC Application Form [RD_Form_04112015]		04 November 2015
Summary of research programme(s) [Summary of research use]	1	17 December 2015

Research governance

A copy of this letter is being sent to the R&D office responsible for NHS Tayside.

Under the Research Governance Framework (RGF), there is no requirement for NHS research permission for the establishment of research databases in the NHS. Applications to NHS R&D offices through IRAS are not required as all NHS organisations are expected to have included management review in the process of establishing the database.

Research permission is also not required by collaborators at data collection centres (DCCs) who provide data under the terms of a supply agreement between the organisation and the database. DCCs are not research sites for the purposes of the RGF.

Database managers are advised to provide R&D offices at all DCCs with a copy of the REC application for information, together with a copy of the favourable opinion letter when available. All DCCs should be listed in Part C of the REC application.

NHS researchers undertaking specific research projects using data supplied by a database must apply for permission to R&D offices at all organisations where the research is conducted, whether or not the database has ethical approval.

Site-specific assessment (SSA) is not a requirement for ethical review of research databases.

Statement of compliance

The Committee is constituted in accordance with the Governance Arrangements for Research Ethics Committees and complies fully with the Standard Operating Procedures for Research Ethics Committees in the UK.

East of Scotland Research Ethics Service REC 1

Attendance at Sub-Committee of the REC meeting on 21 December 2015

Committee Members:

Name	Profession	Present	Notes
Dr Robert Rea	Business Development Manager	Yes	Vice-chair
Dr Graham Cormack	Consultant Ophthalmologist	Yes	
Dr Gary Lyon	Retired	Yes	

Also in attendance:

Name	Position (or reason for attending)
Mrs Lorraine Reilly	Senior Co-ordinator

Written comments received from:

Name	Position
Dr Robert Rea	Business Development Manager, Vice-chair
Dr Graham Cormack	Consultant Ophthalmologist
Dr Gary Lyon	Retired

NHS SCOTLAND
Research Ethics Service

East of Scotland Research Ethics Service (EoSRES)

CONDITIONS OF ETHICAL APPROVAL

Research Ethics Committee:	East of Scotland Research Ethics Service REC 1
Research Database:	Craniofacial Database
Data Controller:	Professor Peter A Mossey
Establishment:	University of Dundee, School of Dentistry
REC reference number:	15/ES/0186
Name of applicant:	Professor Peter A Mossey
Date of approval:	21 December 2015
IRAS project ID:	188096

Ethical approval is given to the Research Database team ("Database team") based within the Establishment by the Research Ethics Committee ("the Committee") subject to the following conditions.

1. Further communications with the Committee

1.1 Further communications with the Committee are the personal responsibility of the applicant.

2. Duration of approval

2.1 Approval is given for a period of 5 years, which may be renewed on consideration of a new application by the Committee, taking account of developments in legislation, policy and guidance in the interim. New applications should include relevant changes of policy or practice made by the establishment since the original approval together with any proposed new developments.

3. Generic approval for the Research Database team

3.1 Ethical approval is given for processing of personal data by the Research Database team for the purposes described in the application. This includes specific research

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projects undertaken by the Database team using the data, subject to the following conditions:

3.1.1 The research project is within the fields of health or social care research described in the application.

3.1.2 The research protocol has been subject to scientific critique, is appropriately designed in relation to its objectives and (with the exception of student research below doctoral level) is likely to add something useful to existing knowledge.

3.1.3 The processing of the data will comply with the terms of informed consent from data subjects.

3.2 Any research project requiring researchers to undertake additional procedures involving subjects, other than data collection arrangements described in the application, is not covered by generic approval for the Database. Additional research procedures should be the subject of further ethical review, either as a substantial amendment to the terms of generic approval for the Database, or separate application for ethical review of a specific project.

3.3 A Notice of Substantial Amendment should be submitted to seek the Committee's agreement to change the conditions of generic approval for the Database.

4. Generic approval for external researchers

4.1 Data may be supplied and used in research projects to be conducted by researchers and research institutions outside of the Research Database team within the UK in accordance with the following conditions.

4.1.1 The research project is within the fields of health or social care research described in the approved application form.

4.1.2 The Research Database team should be satisfied that the research has been subject to scientific critique, is appropriately designed in relation to its objectives and (with the exception of student research below doctoral level) is likely to add something useful to existing knowledge.

4.1.3 Research must be conducted in circumstances such that data subjects are not identifiable to the external researchers. Data must be effectively anonymised or pseudonymised prior to release to external researchers. The researchers should undertake to treat datasets in confidence and not to attempt re-identification of data subjects through linkage with other datasets.

4.1.4 A data sharing agreement must be in place with all external researchers to ensure processing of the data in accordance with the terms of the ethical approval and any other conditions required by the Research Database team.

4.2 A research project using data from the Database in accordance with these conditions will be considered to have ethical approval from the Committee under the terms of this approval.

4.3 Any research project requiring external researchers to be able to identify data subjects for purposes of linkage with other datasets, or in order to collect further data from subjects or their care records or undertake other research procedures involving subjects, is not covered by this approval. Such projects should be the subject of further project-specific application for ethical review.

4.4 The Research Database team may require any researcher to seek specific ethical approval for their project. Such applications should normally be made to the Committee and booked via the Central Booking System.

5. Records

5.1 The establishment should maintain a record of all internal and external research projects using data from the Database. The record should contain at least the full title of the project, a summary of its purpose, the name of the Chief Investigator, the sponsor, the location of the research, the date on which the project was approved by the establishment, a brief summary of the dataset released (including any sensitive data), whether the data was accessed by the researcher in identifiable form, and any relevant reference numbers. For external research, the record should indicate whether data has been released under the terms of the generic approval for the Database or for a project with specific ethical approval.

5.2 The establishment should maintain a risk register and a record of any serious adverse events (see also paragraph 8.1).

5.3 The Committee may request access to these records at any time.

5.4 The Research Database team should maintain a publicly accessible register of research projects using data from the Database.

6. Annual reports

6.1 An annual report should be provided to the Committee listing all projects for which data has been released in the previous year. The list should give the full title of each project, the name of the Chief Investigator, the sponsor, the location of the research and the date of approval by the establishment. The report is due on the anniversary of the date on which ethical approval for the Database was given.

6.2 The Committee may request additional reports on the management of the Database at any time.

7. Substantial amendments

7.1 Substantial amendments should be notified to the Committee and ethical approval sought before implementing the amendment. A substantial amendment generally means any significant change to the arrangements for the management of the Database as described in the application to the Committee and supporting documentation.

7.2 A Notice of Substantial Amendment should be generated by accessing the original application form on the Integrated Research Application System (IRAS).

7.3 The following changes should always be notified as substantial amendments:

7.3.1 Any significant change to the policy for use of the data in research, including changes to the types of research to be undertaken or supported by the establishment.

7.3.2 Any significant change to the types of data to be collected and stored, or the circumstances of collection.

7.3.3 Any significant change to informed consent arrangements, including new/modified information sheets and consent forms.

7.3.4 Any proposed change to the conditions of approval

7.3.5 Any other significant change to the location, management or governance of the Database.

8. Serious adverse events

8.1 The Committee should be notified as soon as possible of any serious adverse event or reaction, any serious breach of security or confidentiality, or any other incident that could undermine public confidence in the ethical management of the data.

9. Changes in responsibility

9.1 The Committee should be notified of any change in the contact details for the applicant or where the applicant hands over responsibility for communication with the Committee to another person at the establishment.

10. **Closure of the Database**

10.1 Any plans to close the Database should be notified to the Committee as early as possible and at least two months before closure. The Committee should be informed of the arrangements to be made for destruction of the data or transfer to another research database or archive, and of the arrangements to notify data subjects where appropriate.

10.2 Where data is transferred to another research database ("the second database") or archive, the ethical approval for the Database is not transferable. Where the second database is ethically approved, it should notify the responsible Research Ethics Committee. The terms of its own ethical approval would apply to any data it receives. If the second database is not ethically approved, the responsible establishment may seek ethical approval by submitting a new application to the Committee.

10.3 Where data is transferred to another research database, any projects already underway using data supplied from the Database in accordance with these conditions continue to have ethical approval for the duration of those projects.

11. Compliance with approval conditions

11.1 Oversight mechanisms should be in place to ensure these approval conditions are complied with. Compliance is the personal responsibility of the Data Controller.

11.2 The Committee should be notified as soon as possible of any breach of these conditions.

11.3 Where serious breaches occur, the Committee may review its ethical approval and may, exceptionally, suspend or terminate the approval.

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Scottish Sample

CASE #	SEX	AGE	Malocclusion
1	F	12	Class I
2	M	13	Class I
3	M	12	Class I
4	M	14	Class I
5	F	14	Class I
6	M	13	Class I
7	F	12	Class I
8	M	13	Class I
9	F	14	Class I
10	F	14	Class I
11	M	14	Class I
12	M	13	Class I
13	F	13	Class I
14	F	12	Class I
15	F	14	Class III
16	F	11	Class III
17	F	12	Class III
18	M	11	Class III
19	M	14	Class III
20	F	12	Class III
21	M	13	Class III
22	F	12	Class III
23	M	13	Class III
24	F	14	Class III
25	F	14	Class III
26	M	13	Class III
27	M	11	Class III
28	M	13	Class III
29	M	12	Class II div 1
30	F	11	Class II div 1
31	M	14	Class II div 1
32	M	12	Class II div 1
33	M	14	Class II div 1
34	M	11	Class II div 1
35	F	12	Class II div 1
36	F	12	Class II div 1
37	F	14	Class II div 1
38	M	13	Class II div 1
39	M	12	Class II div 1
40	F	11	Class II div 1
41	F	13	Class II div 1

CASE #	SEX	AGE	Malocclusion
42	F	13	Class II div 1
43	M	14	Class II div 2
44	F	14	Class II div 2
45	M	14	Class II div 2
46	M	12	Class II div 2
47	F	12	Class II div 2
48	M	13	Class II div 2
49	M	12	Class II div 2
50	F	12	Class II div 2
51	F	13	Class II div 2
52	F	14	Class II div 2
53	F	14	Class II div 2
54	F	14	Class II div 2
55	M	11	Class II div 2
56	M	13	Class II div 2

Table I-1: *Raw Scottish data analysed in the present study. All participants received orthodontic treatment in Dental Hospital/ University of Dundee.*

Jordanian Sample

CASE #	SEX	AGE	Malocclusion
1	F	12	Class I
2	M	14	Class I
3	M	13	Class I
4	F	11	Class I
5	F	12	Class I
6	M	13	Class I
7	M	13	Class I
8	F	14	Class I
9	M	14	Class I
10	F	13	Class I
11	F	13	Class I
12	F	14	Class I
13	M	13	Class I
14	M	14	Class I
15	M	12	Class III
16	M	13	Class III
17	M	13	Class III
18	F	13	Class III
19	M	14	Class III

CASE #	SEX	AGE	Malocclusion
20	M	11	Class III
21	F	12	Class III
22	M	14	Class III
23	M	14	Class III
24	F	13	Class III
25	F	14	Class III
26	F	11	Class III
27	F	14	Class III
28	F	13	Class III
29	M	14	Class II div 1
30	M	11	Class II div 1
31	F	12	Class II div 1
32	F	13	Class II div 1
33	F	13	Class II div 1
34	M	12	Class II div 1
35	M	13	Class II div 1
36	F	12	Class II div 1
37	F	13	Class II div 1
38	M	13	Class II div 1
39	M	14	Class II div 1
40	F	11	Class II div 1
41	F	11	Class II div 1
42	M	13	Class II div 1
43	F	11	Class II div 2
44	F	13	Class II div 2
45	F	14	Class II div 2
46	F	14	Class II div 2
47	F	13	Class II div 2
48	M	12	Class II div 2
49	M	11	Class II div 2
50	M	13	Class II div 2
51	M	12	Class II div 2
52	M	11	Class II div 2
53	F	12	Class II div 2
54	F	12	Class II div 2
55	M	13	Class II div 2
56	M	14	Class II div 2

Table I-2: *Raw Jordanian data analysed in the present study. All participants received orthodontic treatment in Jordan University Hospital.*

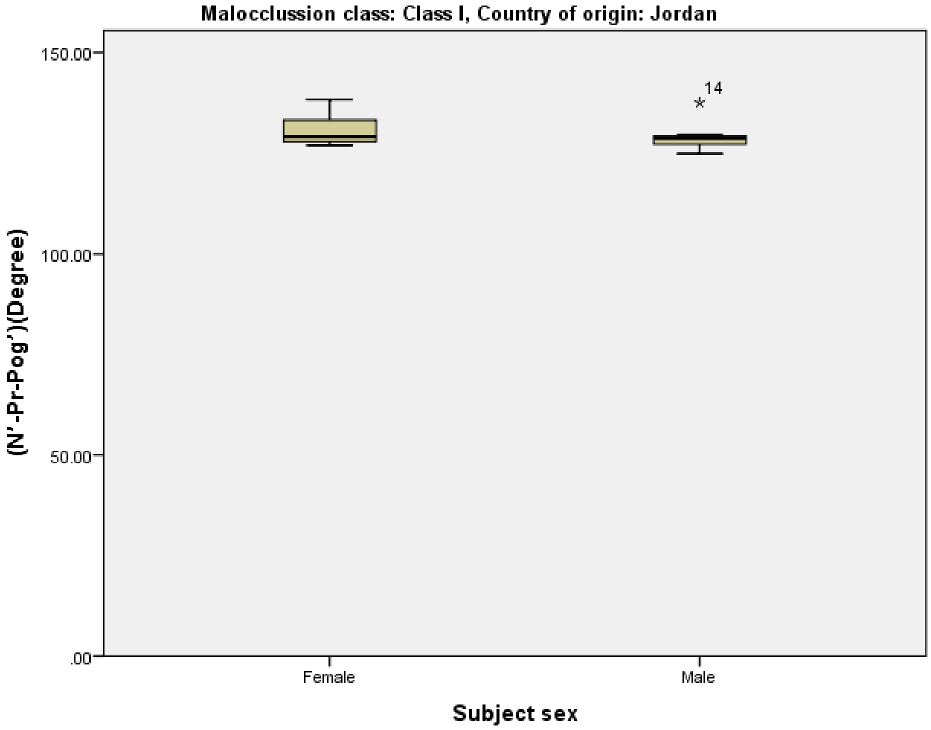
Frequencies

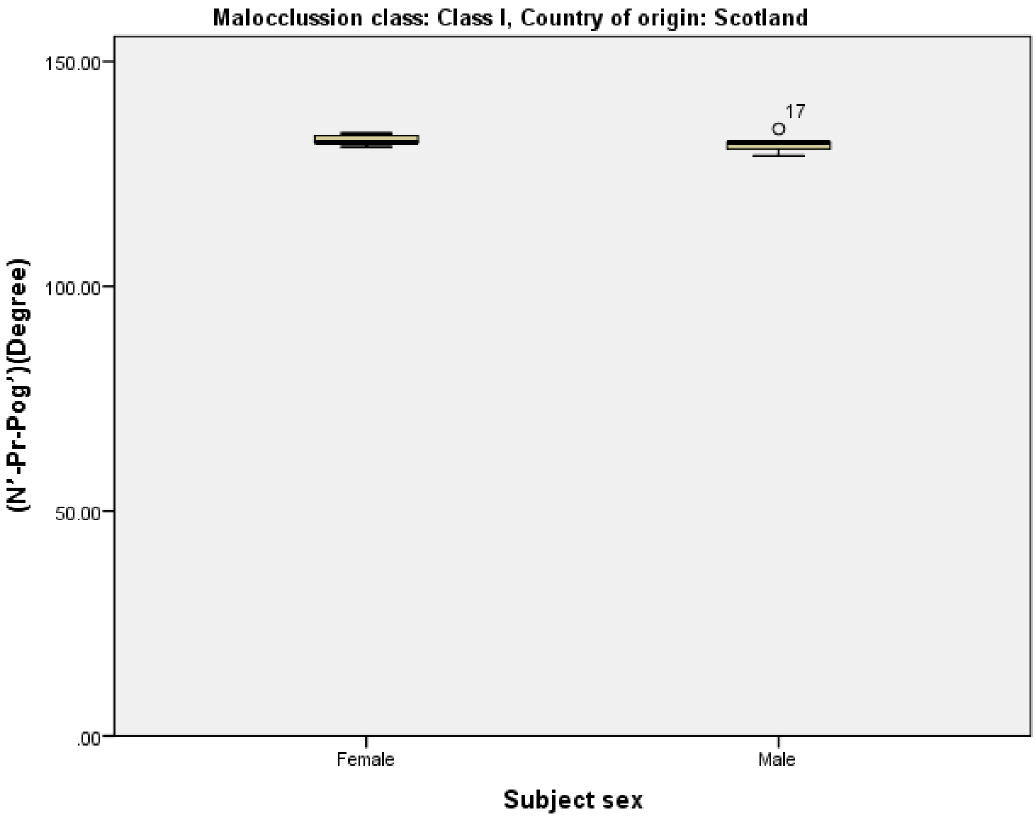
Country of origin			Age (Years)	Sex	Malocclusion class
Jordan	N	Valid	56	56	56
		Missing	0	0	0
	Mean		12.75		
	Median		13.00		
	Std. Deviation		1.031		
	Minimum		11		
	Maximum		14		
Scotland	N	Valid	56	56	56
		Missing	0	0	0
	Mean		12.79		
	Median		13.00		
	Std. Deviation		1.039		
	Minimum		11		
	Maximum		14		

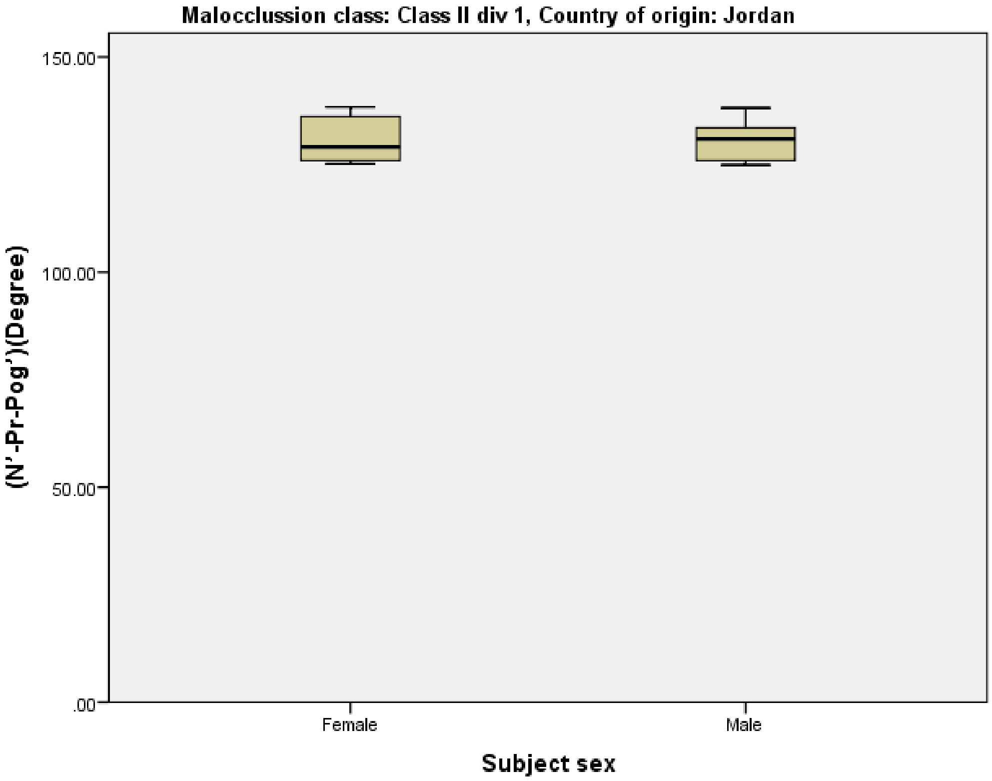
Table I-3: *The Frequency analysis of age in the Jordanian and Scottish sample.*

Appendix II

Normality and outliers results using boxplot graphs







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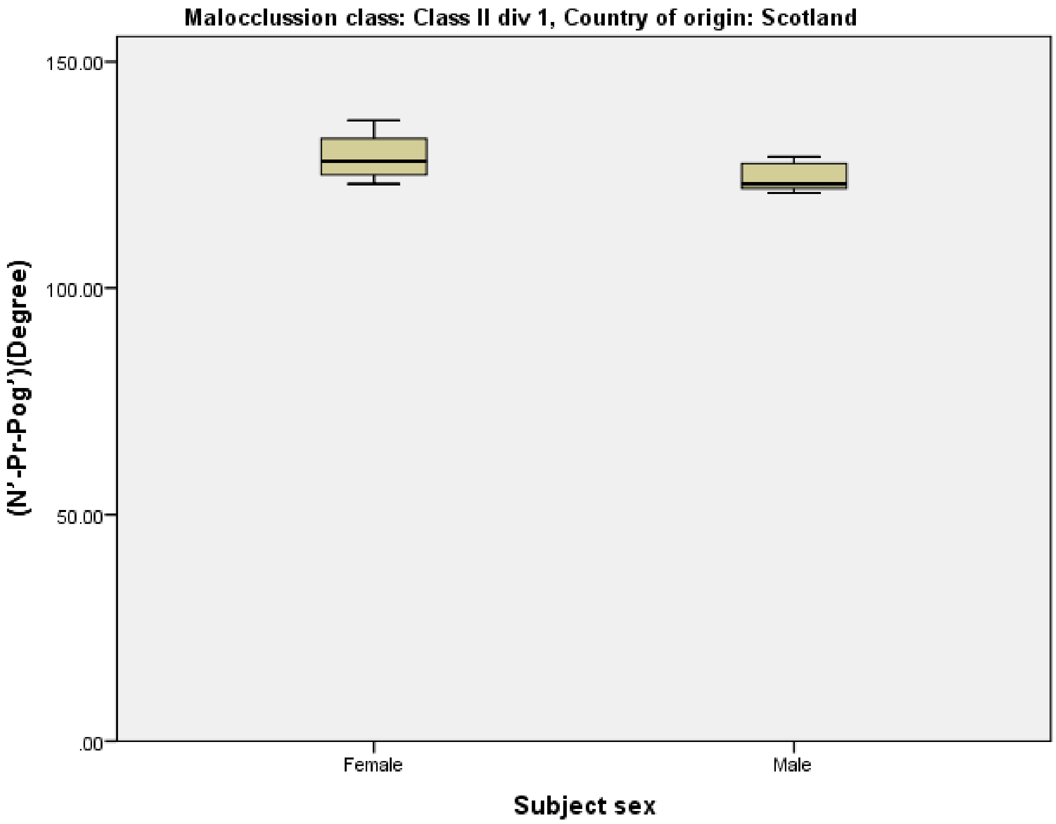

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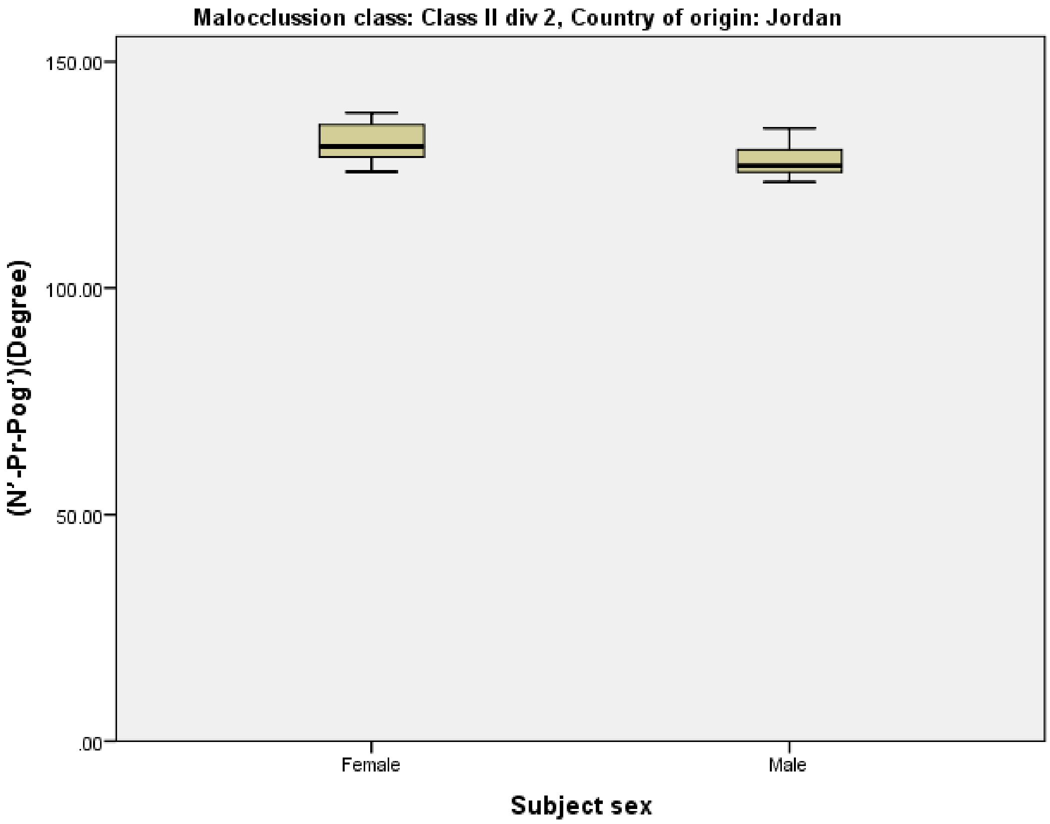
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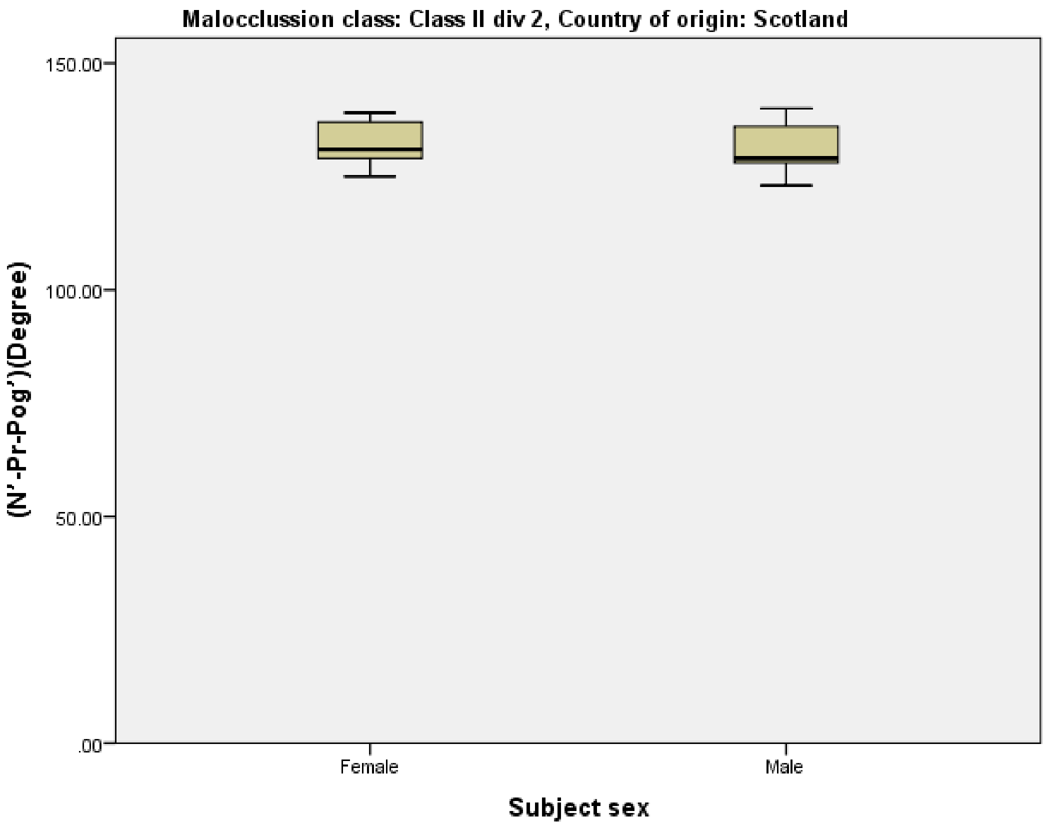
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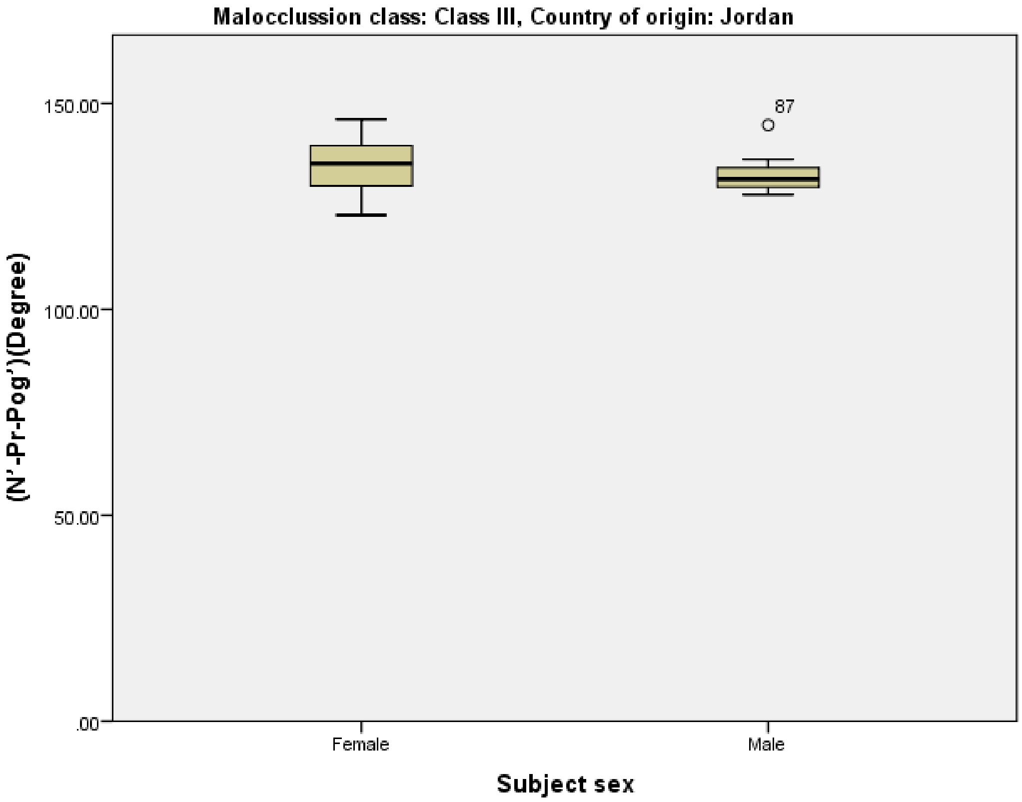
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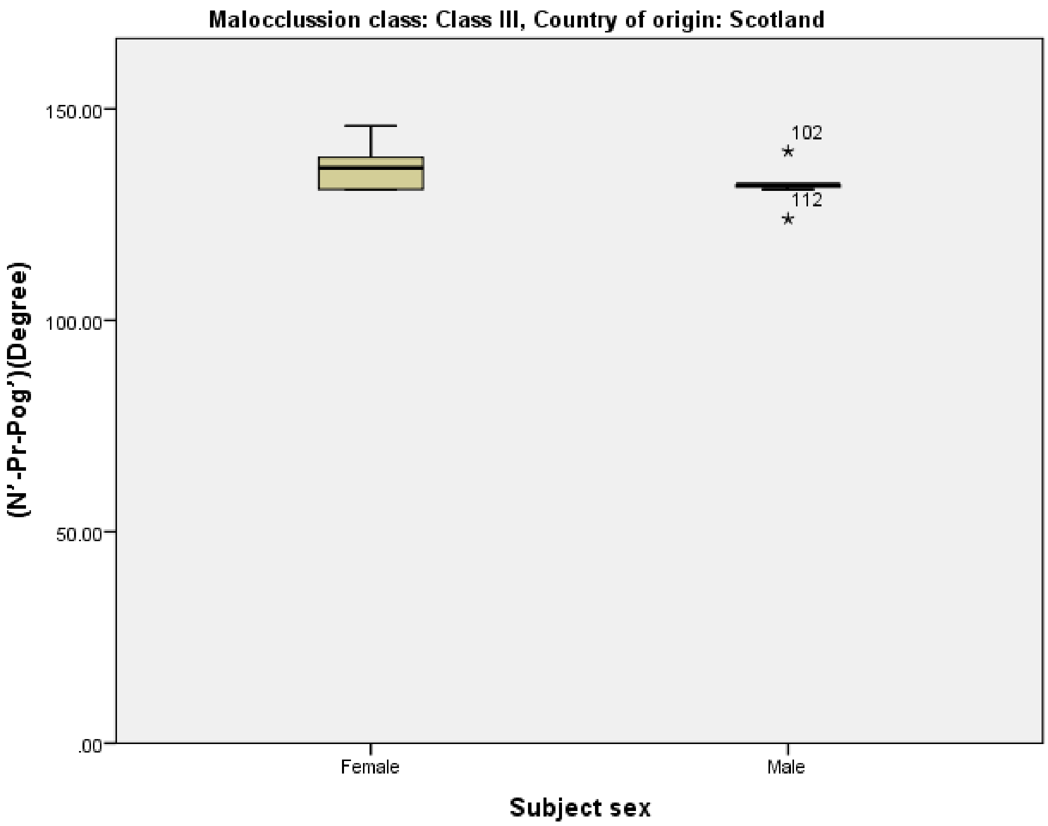
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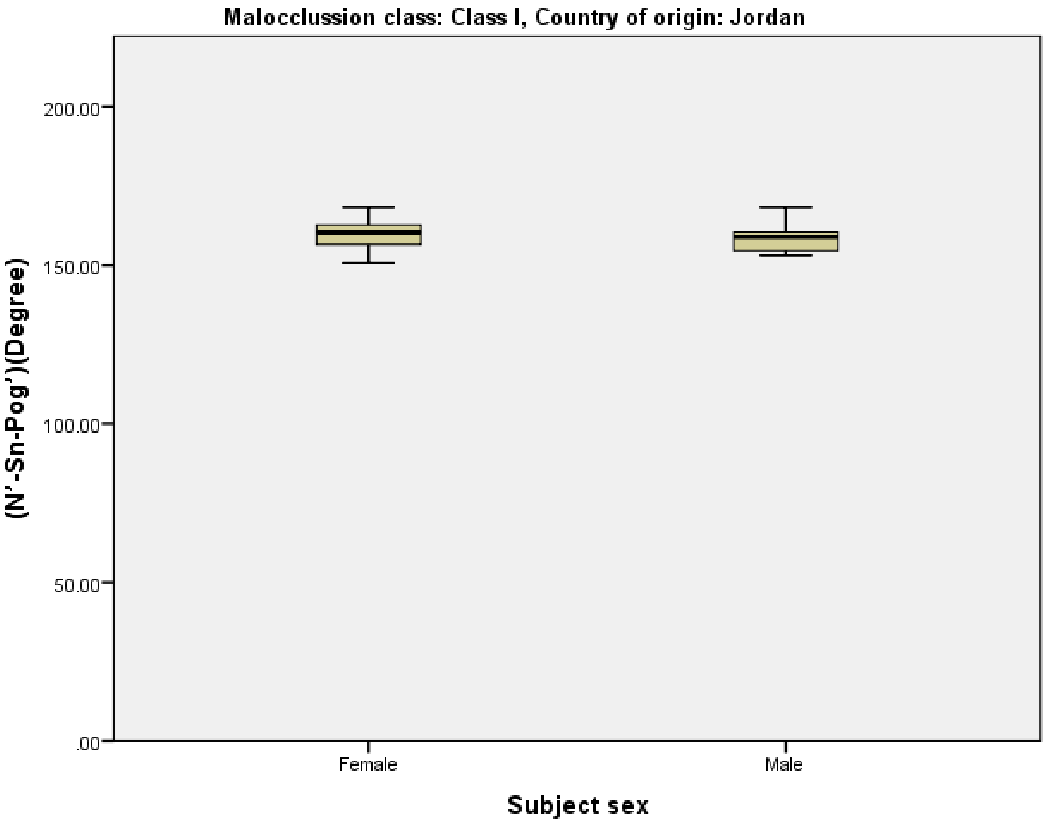
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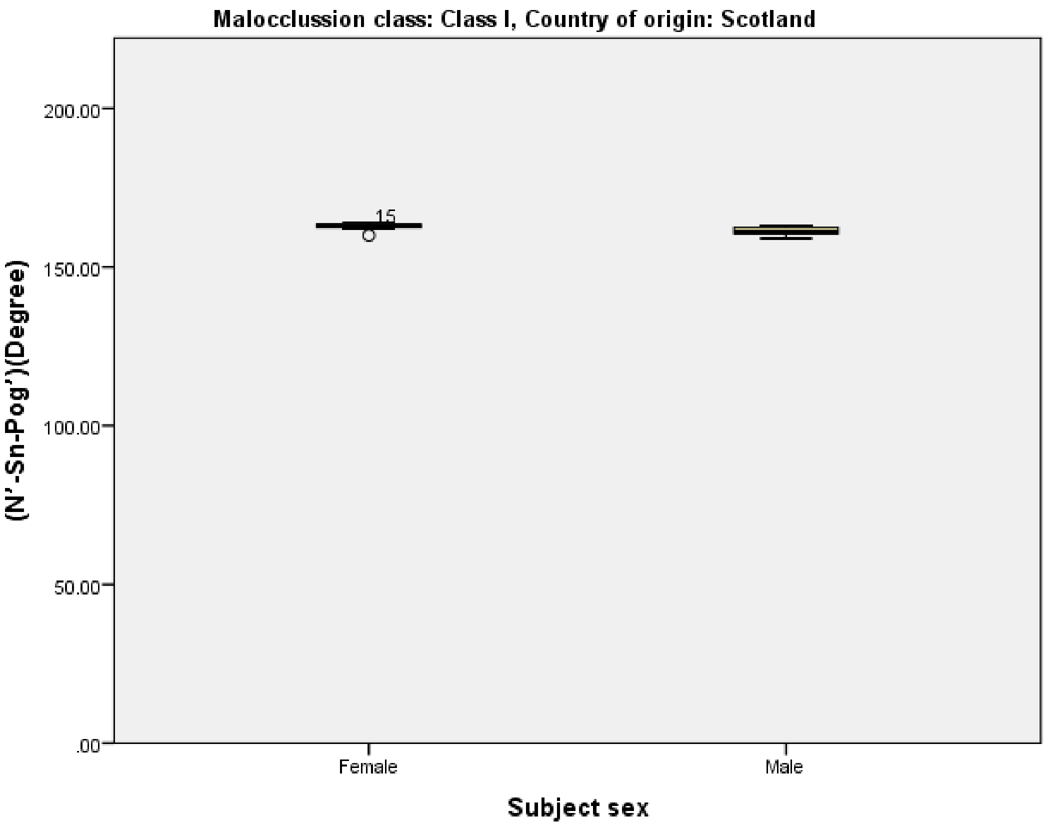
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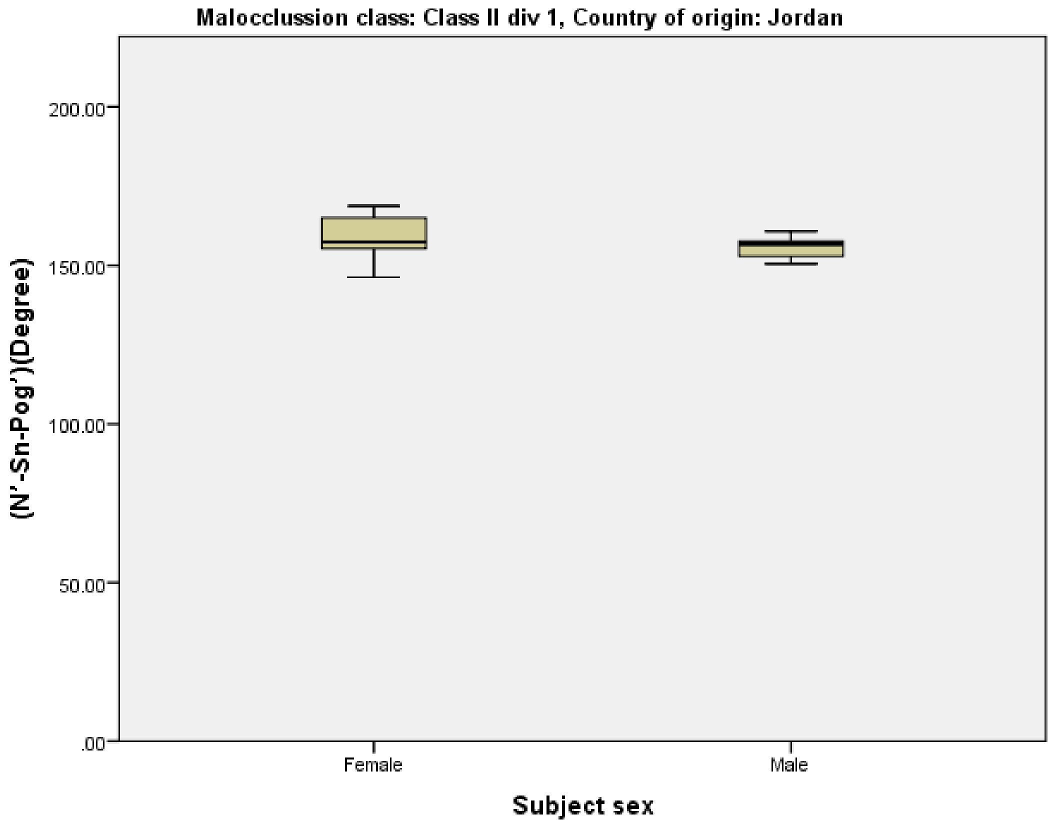
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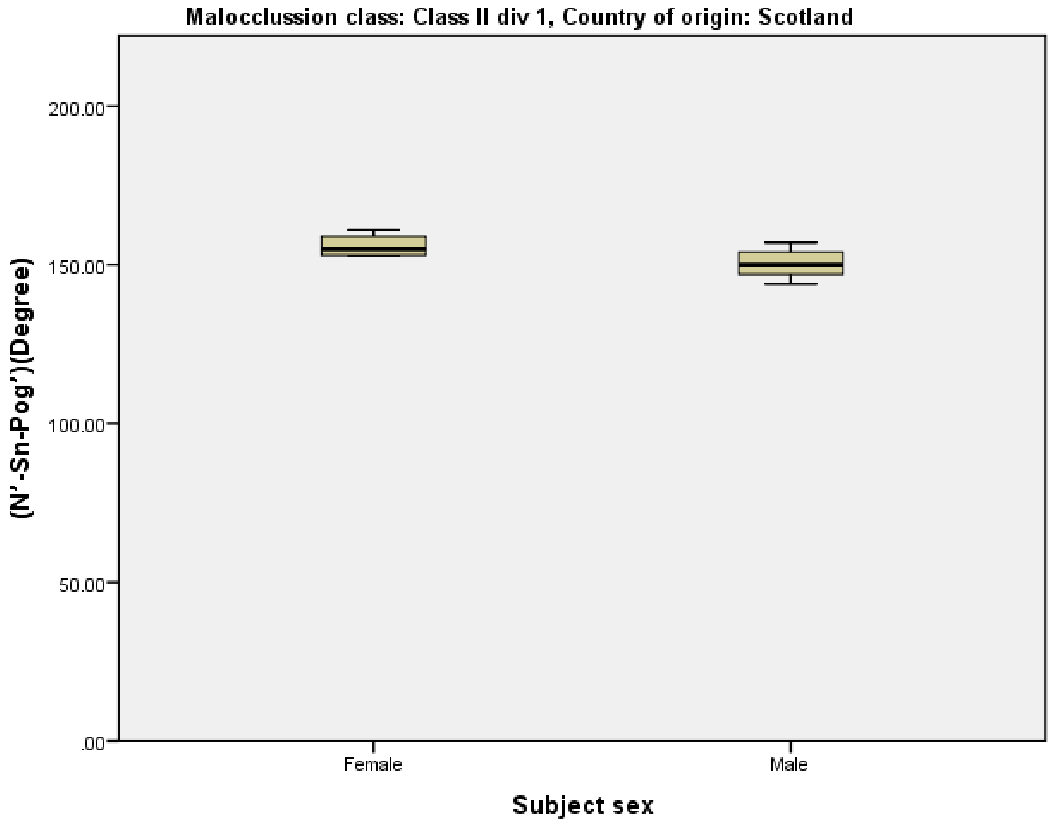
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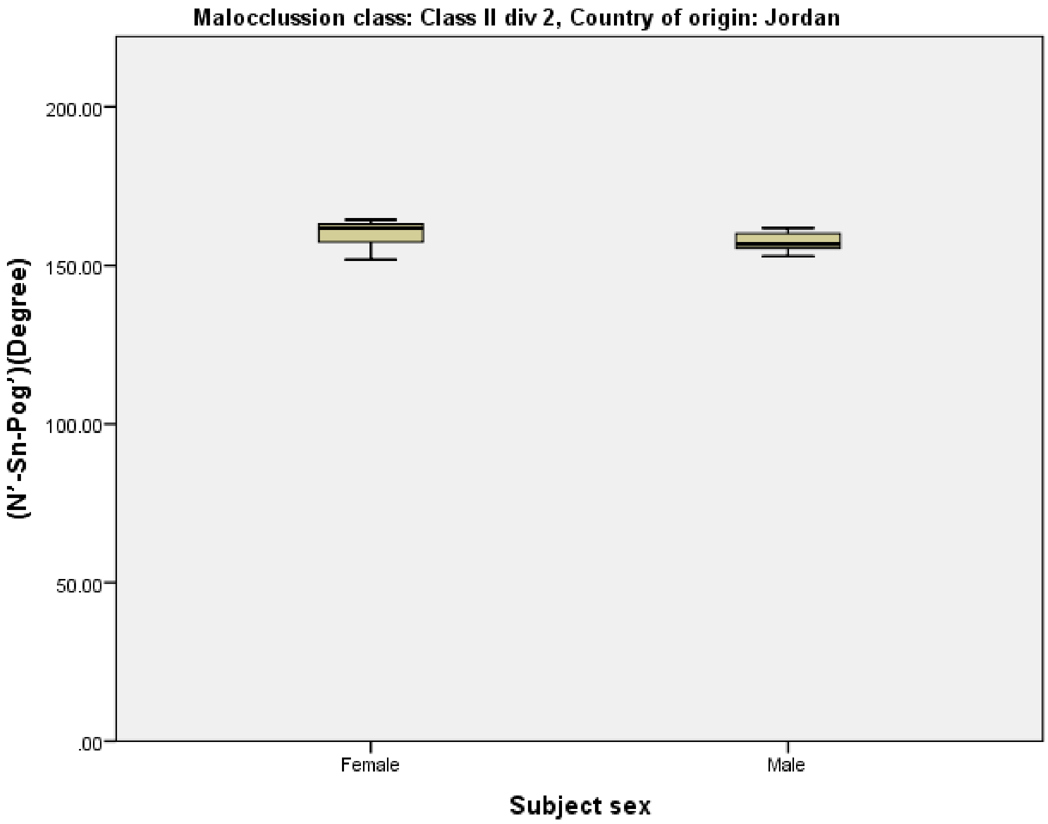
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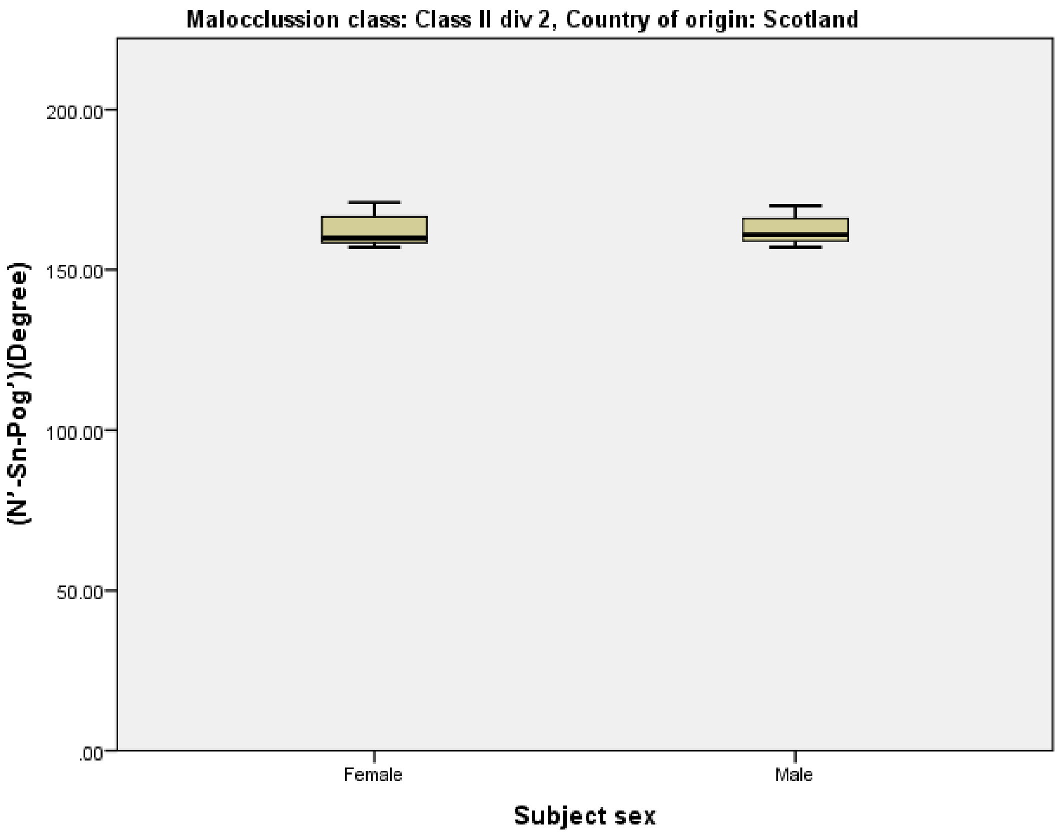
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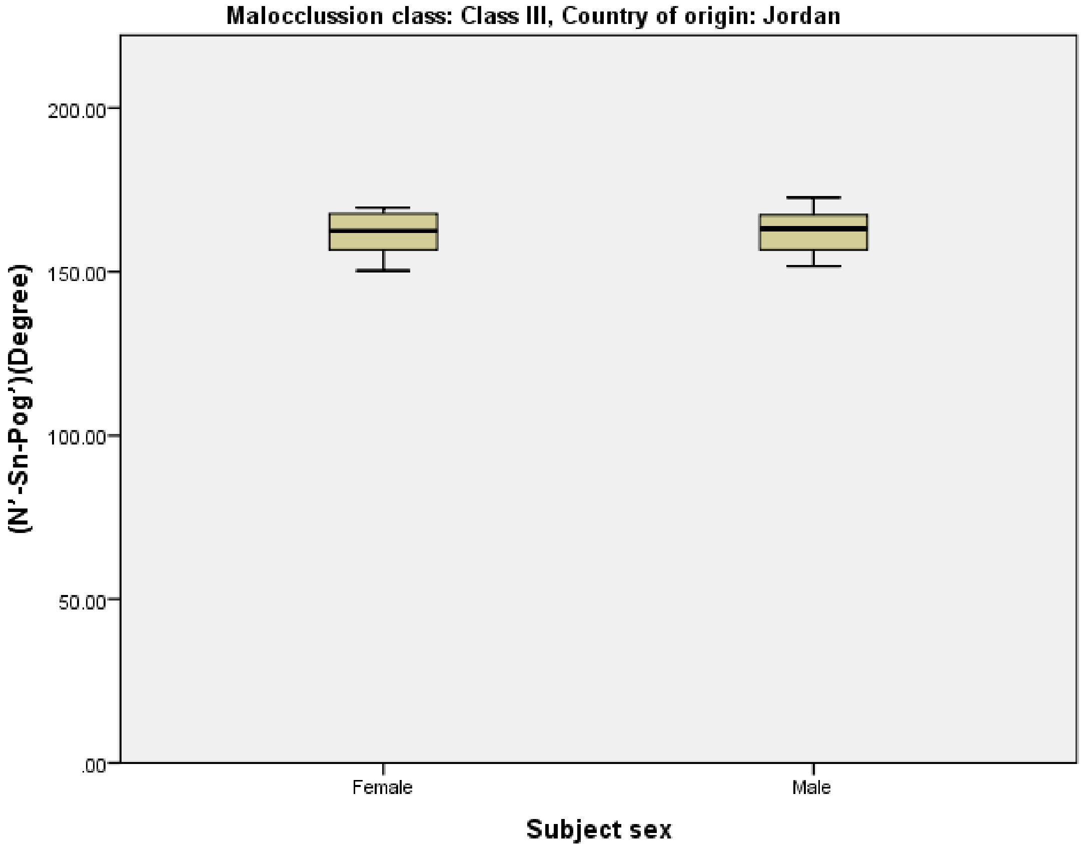
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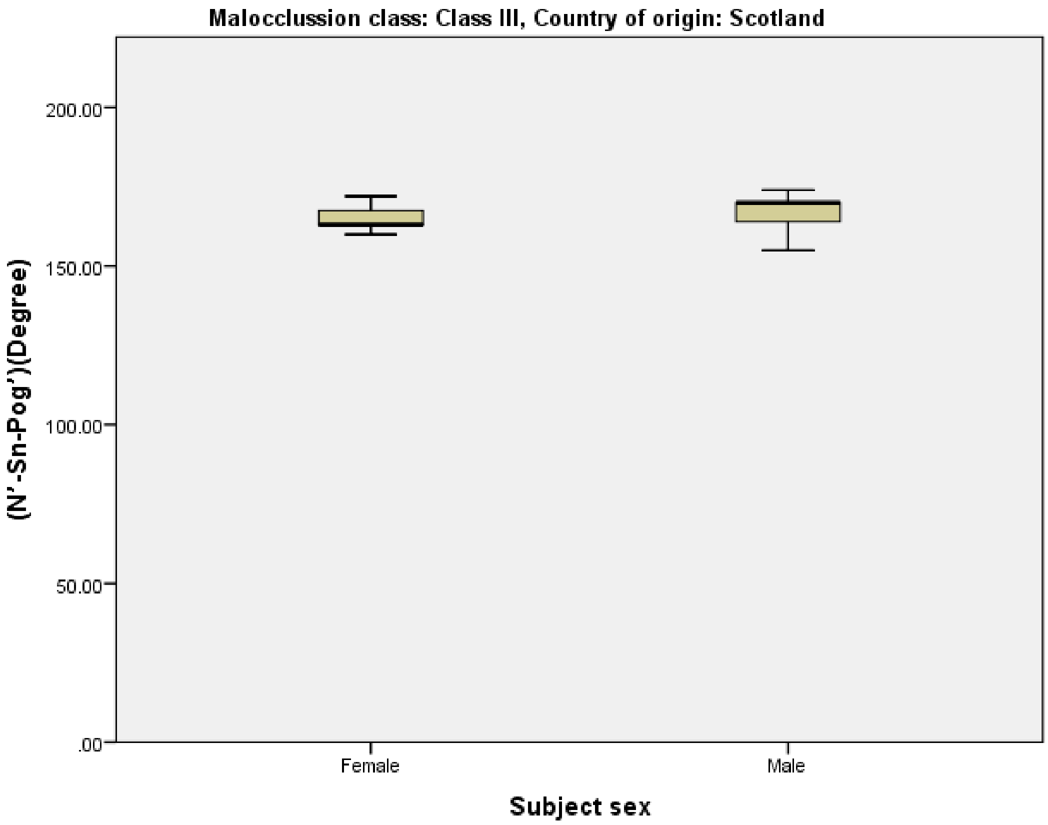
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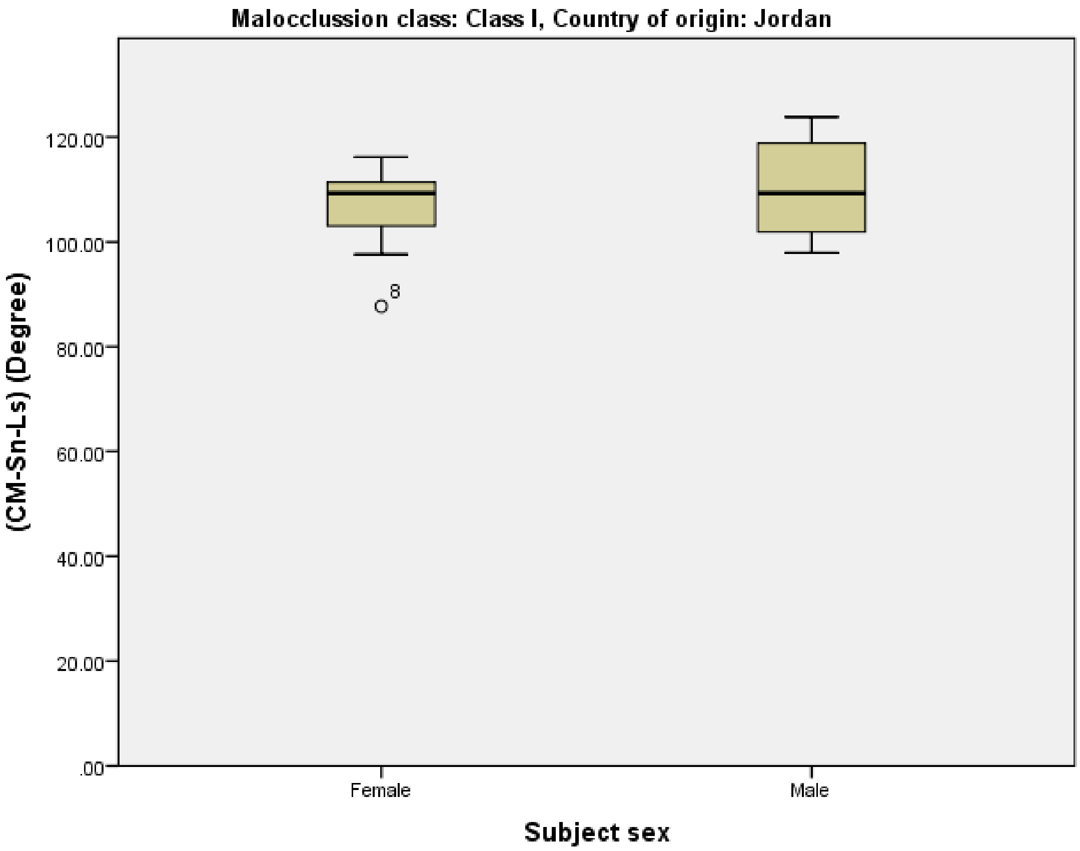
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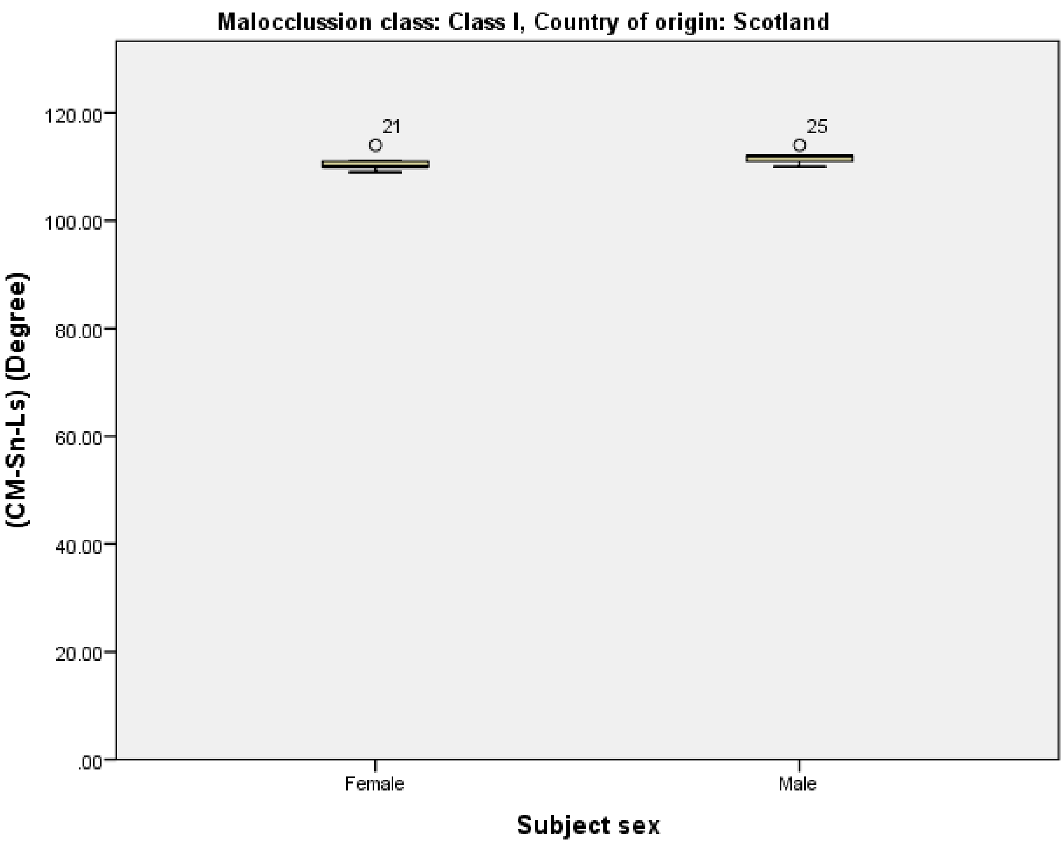
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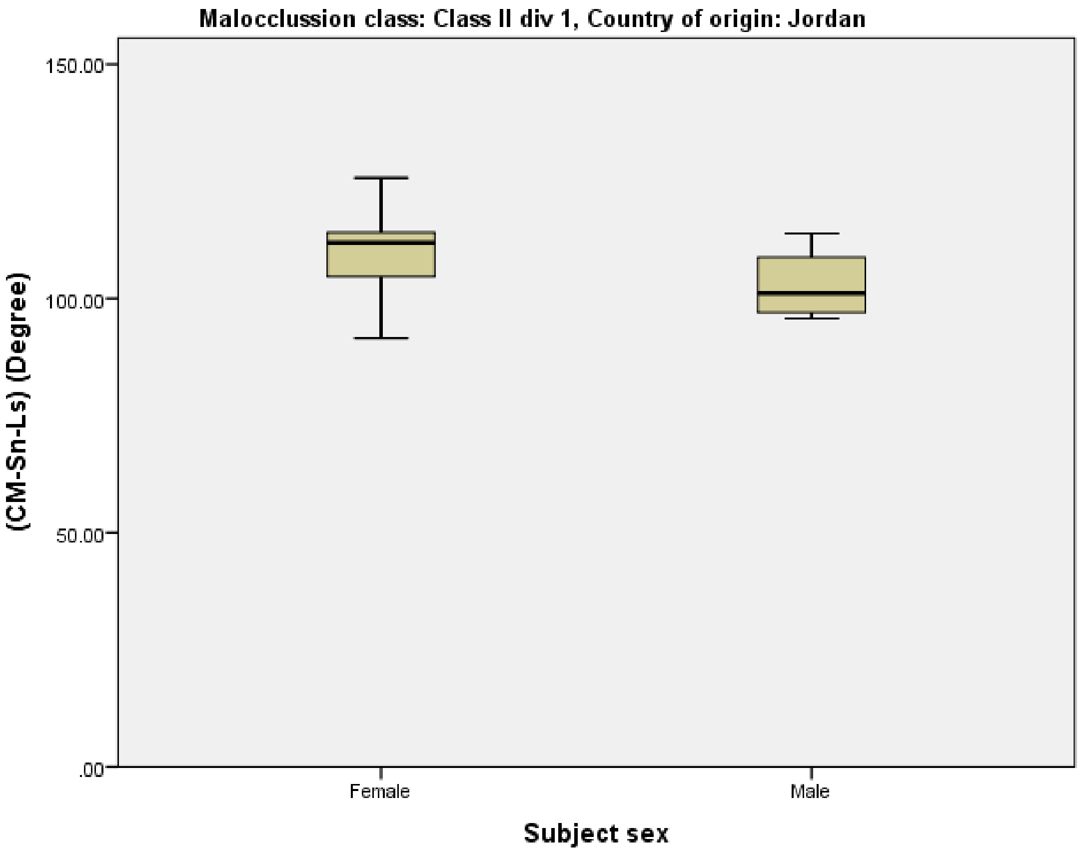
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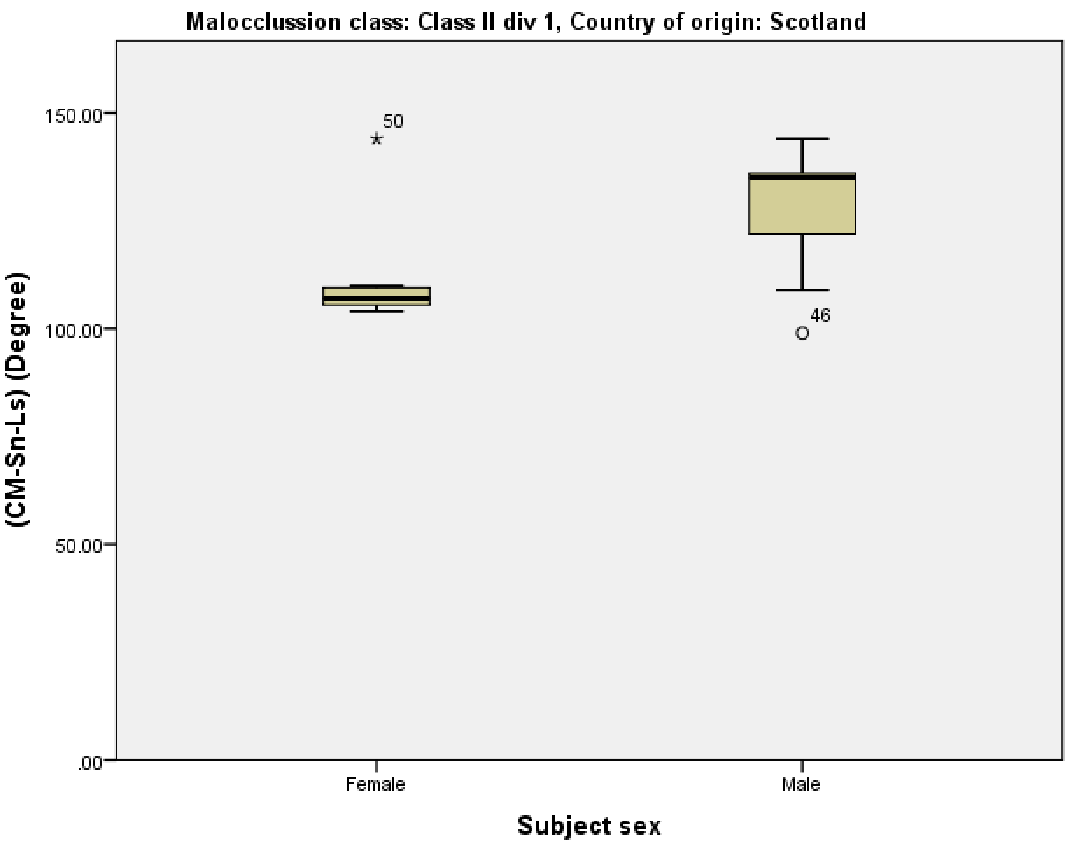
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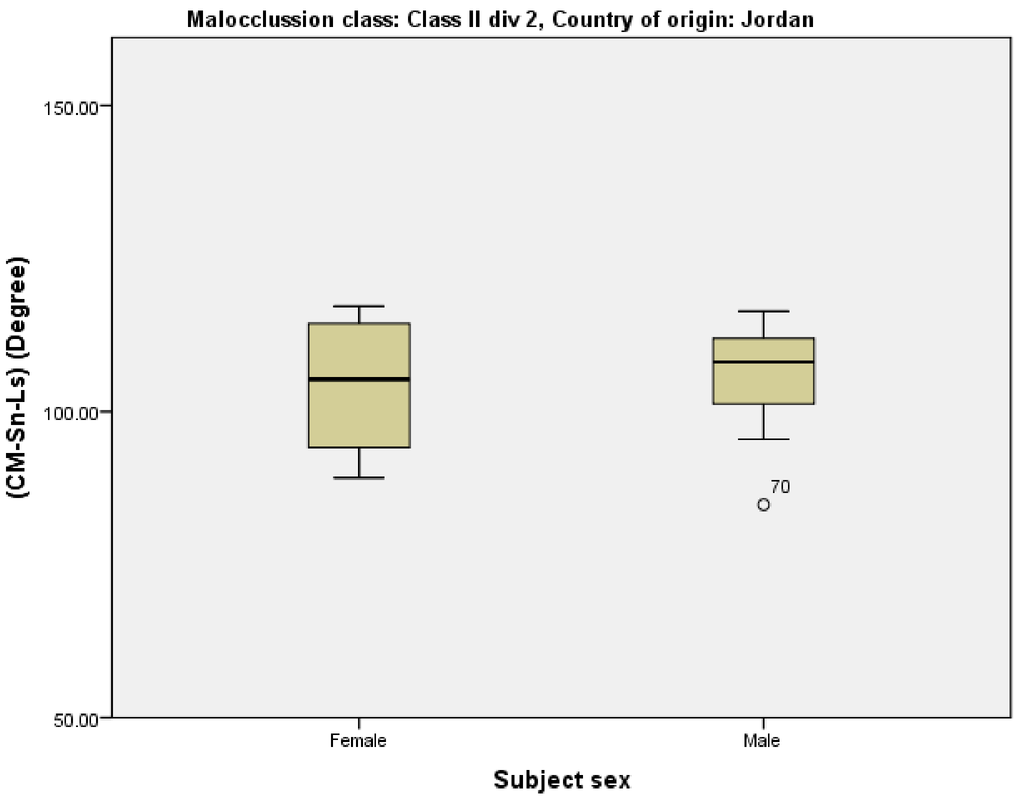
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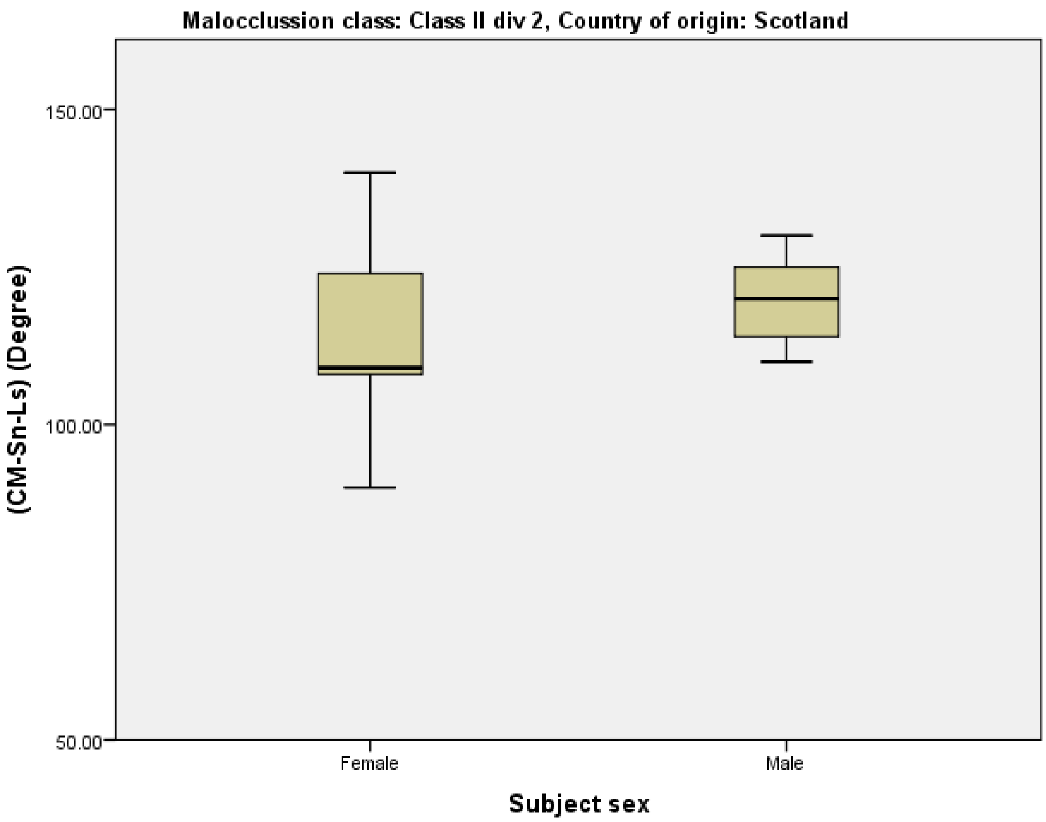
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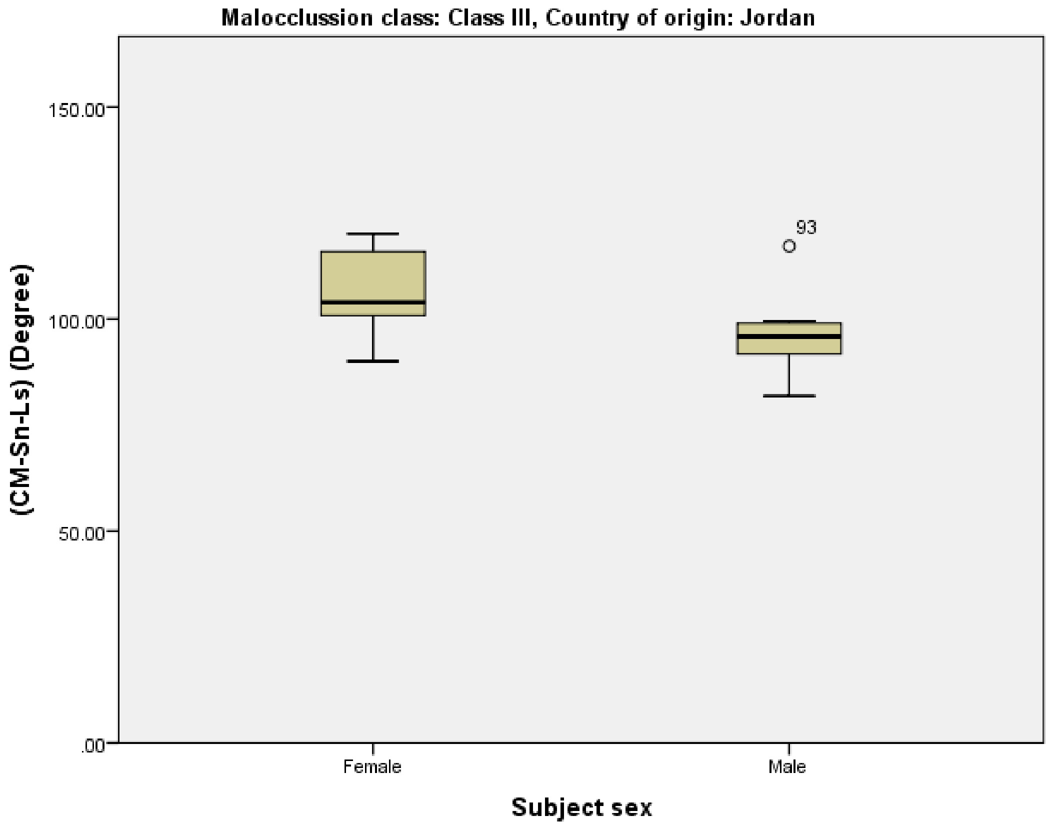
50.00
(CM-Sn-Ls) (Degree)
Female
Male
Subject sex


Malocclussion class: Class III, Country of origin: Jordan
150.00
100.00
50.00
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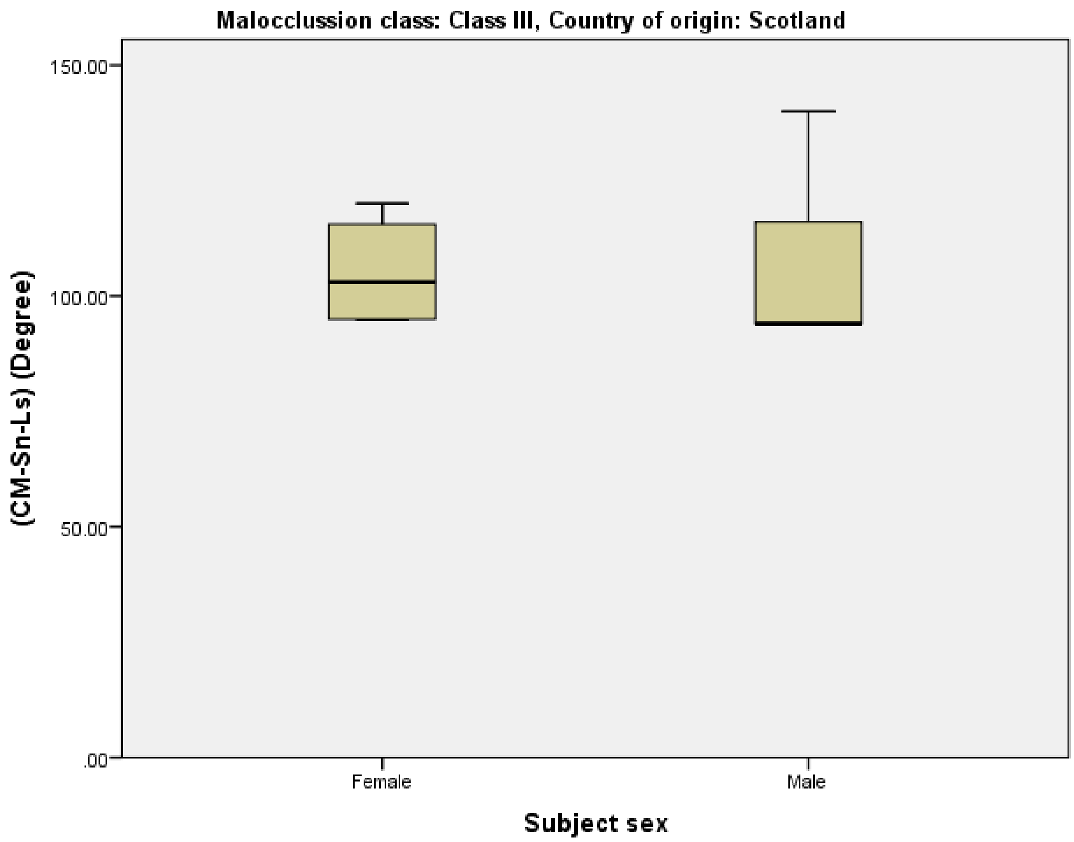
93
(CM-Sn-Ls) (Degree)
Female
Male
Subject sex


Malocclussion class: Class III, Country of origin: Scotland
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50.00
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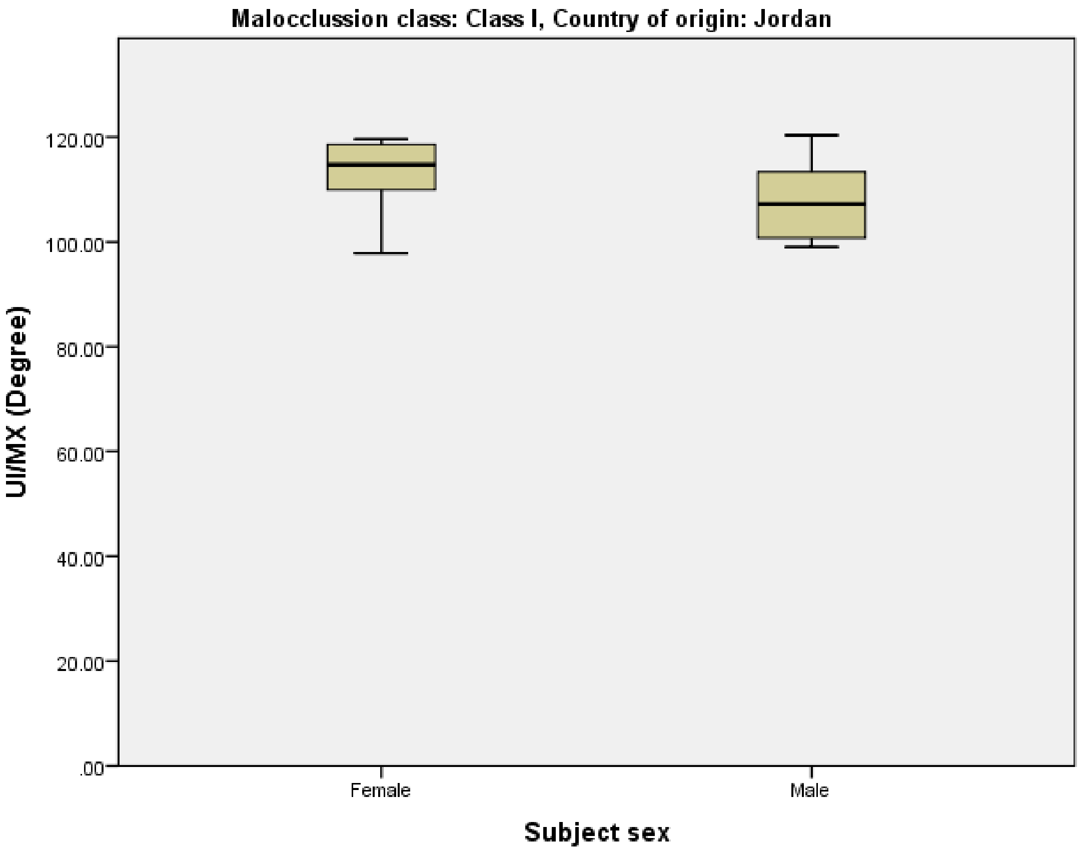
(CM-Sn-Ls) (Degree)
Female
Male
Subject sex


Malocclussion class: Class I, Country of origin: Jordan
UI/MX (Degree)
120.00
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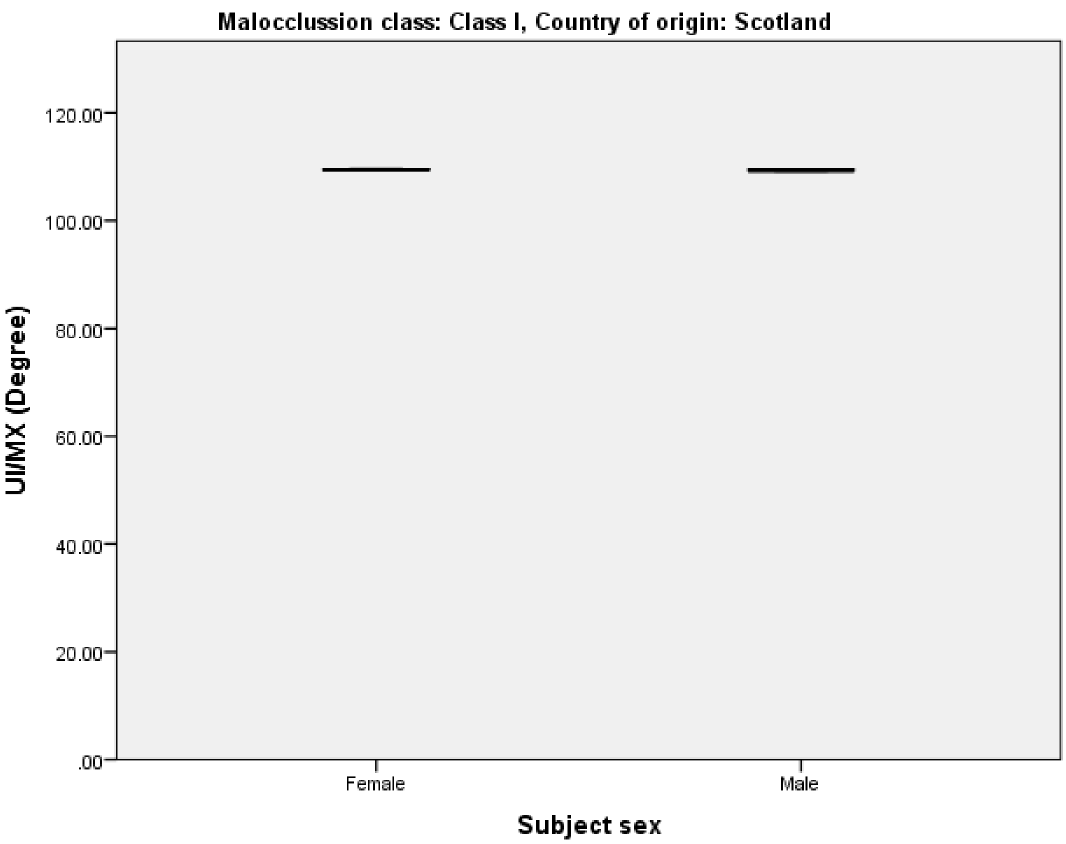
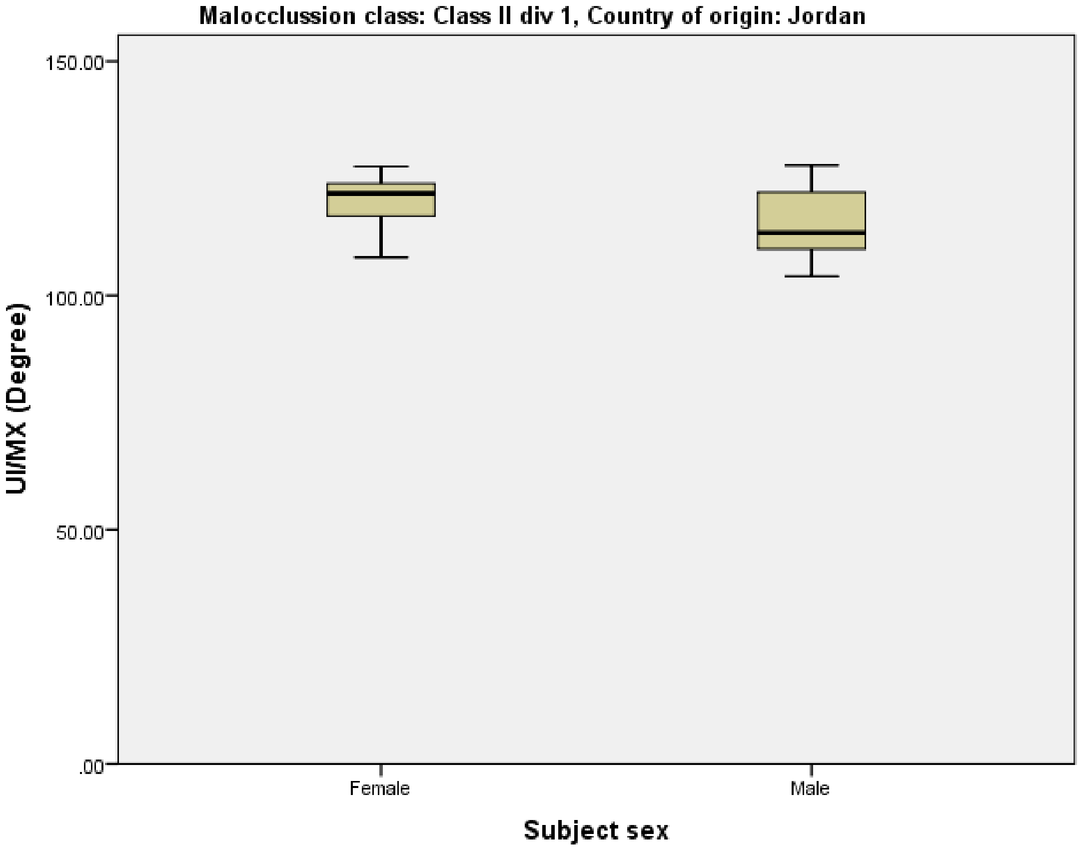
80.00
60.00
40.00
20.00
.00
Female
Male
Subject sex


Malocclussion class: Class I, Country of origin: Scotland
UI/MX (Degree)
120.00
100.00
80.00
60.00
40.00
20.00
.00
Female
Male
Subject sex


Malocclussion class: Class II div 1, Country of origin: Jordan
UI/MX (Degree)
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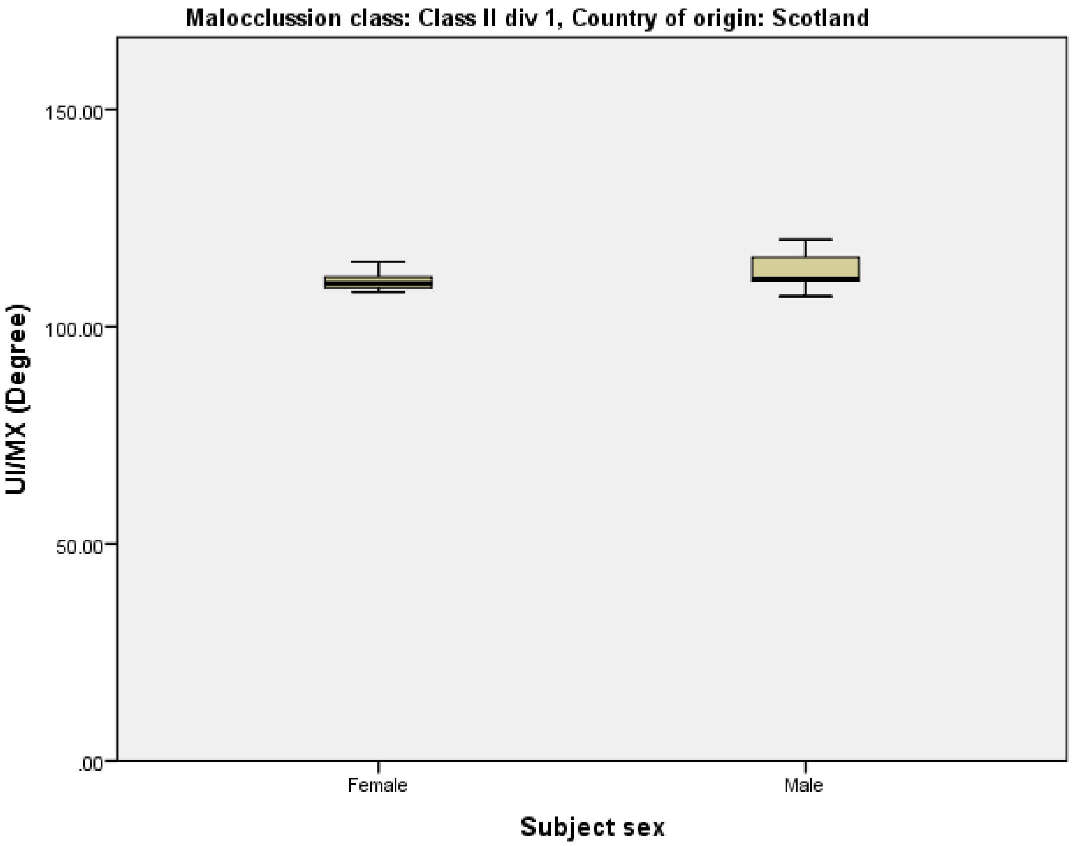
100.00
50.00
.00
Female
Male
Subject sex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UI/MX (Degree)
150.00
100.00
50.00
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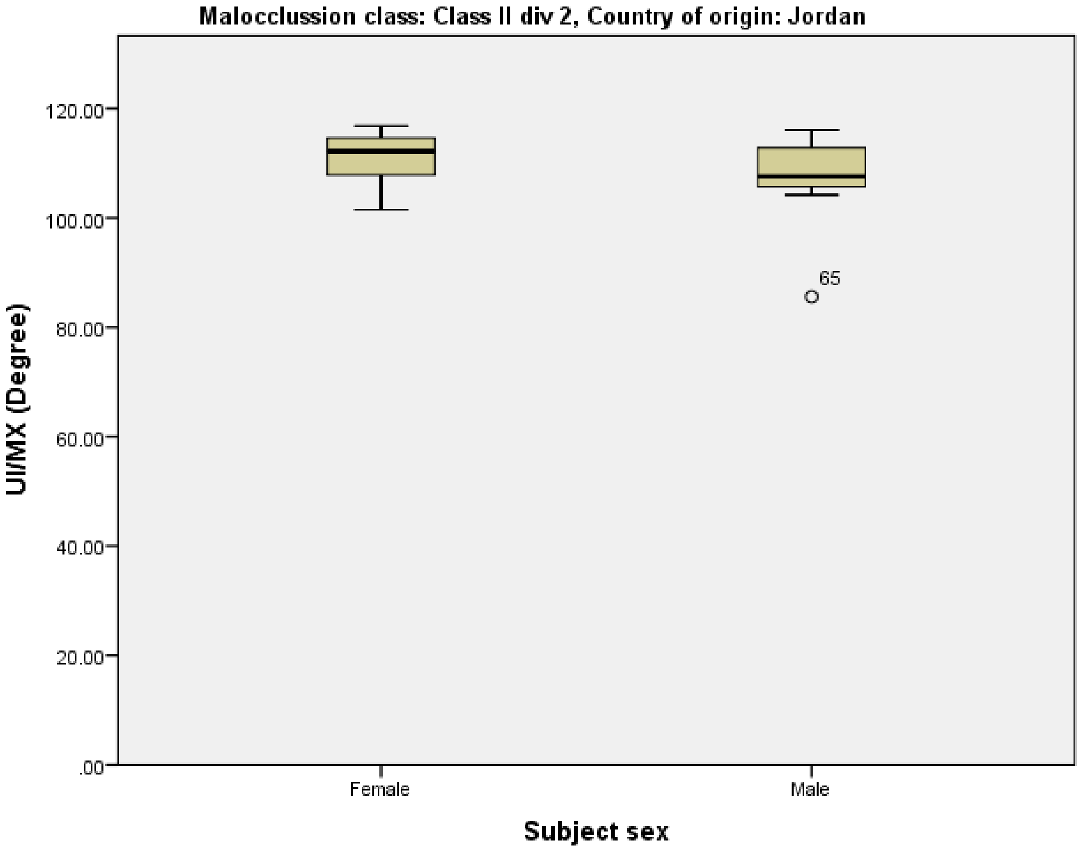
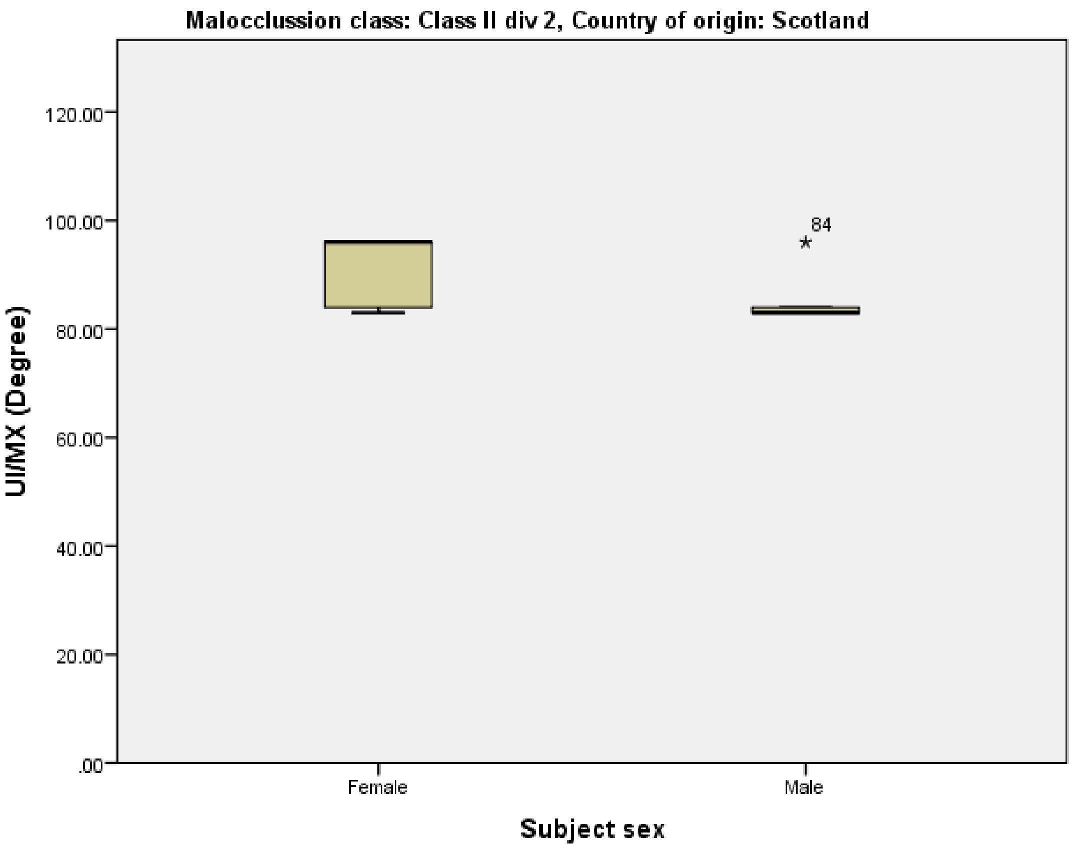
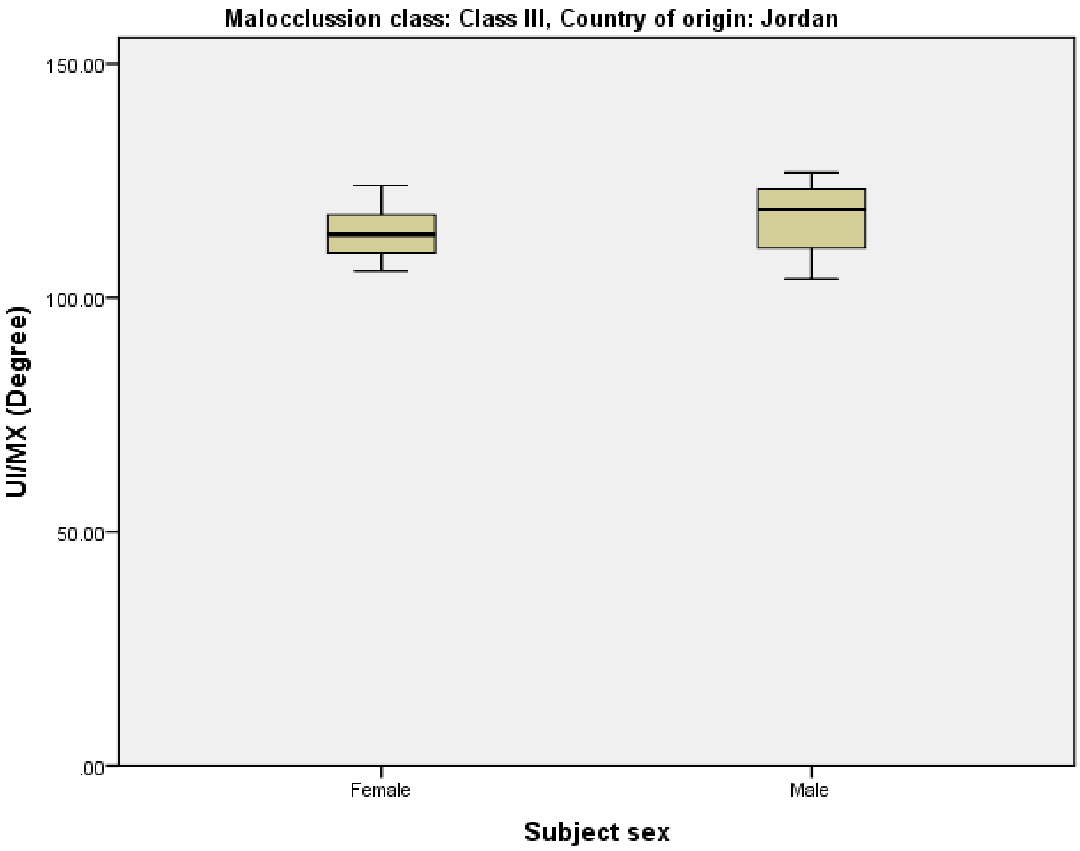
Female
Male
Subject sex


Malocclussion class: Class II div 2, Country of origin: Jordan
UI/MX (Degree)
120.00
100.00
80.00
60.00
40.00
20.00
.00
65
Female
Male
Subject sex


Malocclussion class: Class II div 2, Country of origin: Scotland
UI/MX (Degree)
120.00
100.00
80.00
60.00
40.00
20.00
.00
84
Female
Male
Subject sex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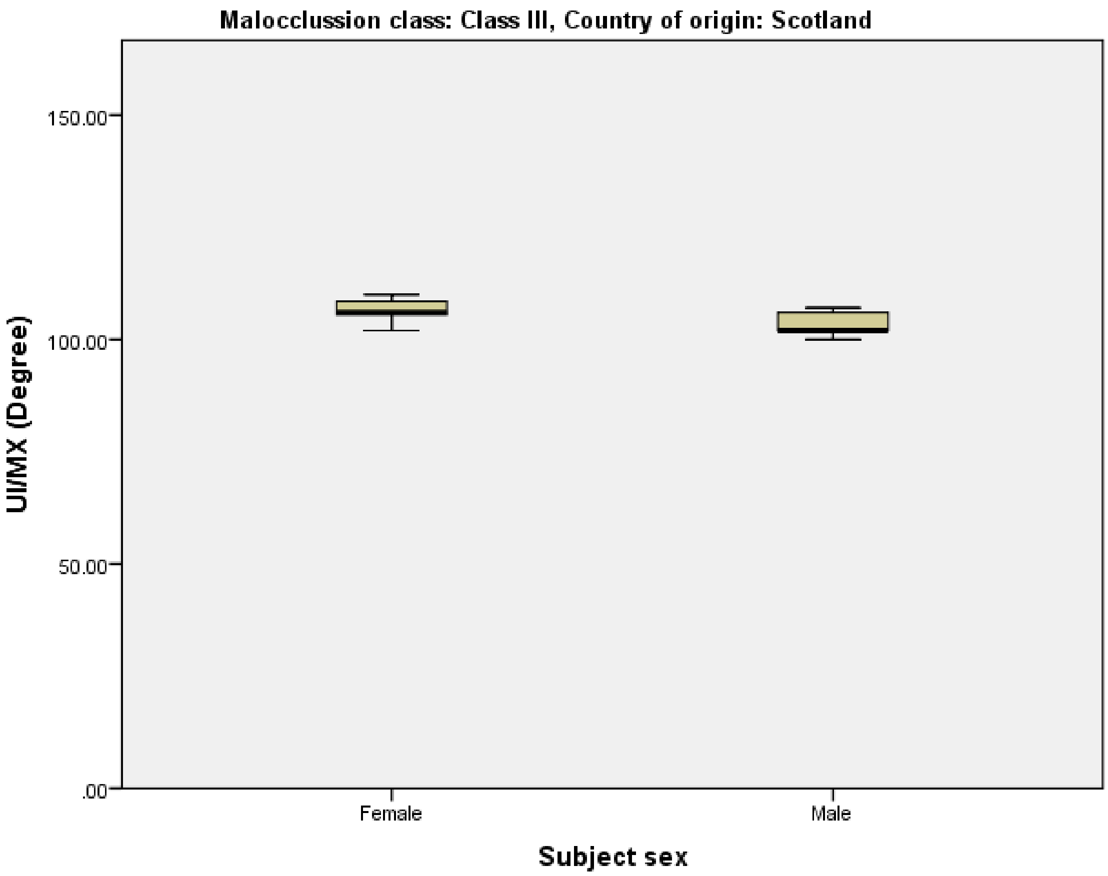
UI/MX (Degree)
150.00
100.00
50.00
.00
Female
Male
Subject sex


Malocclussion class: Class III, Country of origin: Scotland
UI/MX (Degree)
150.00
100.00
50.00
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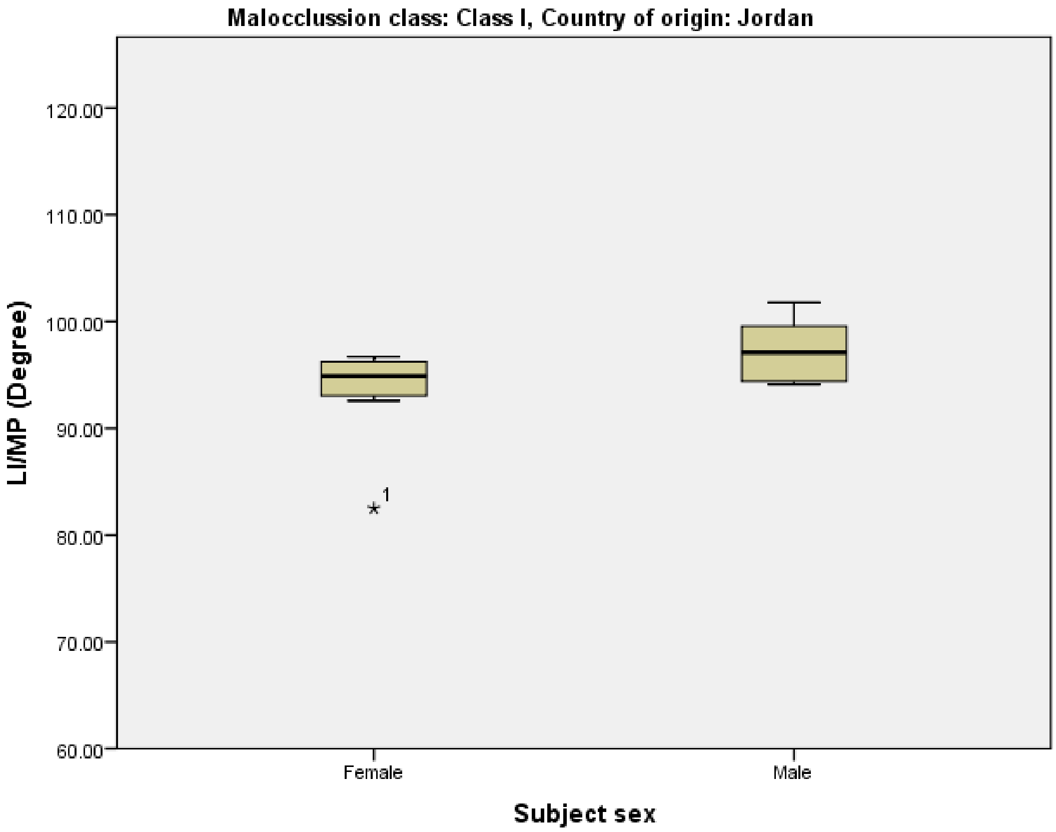
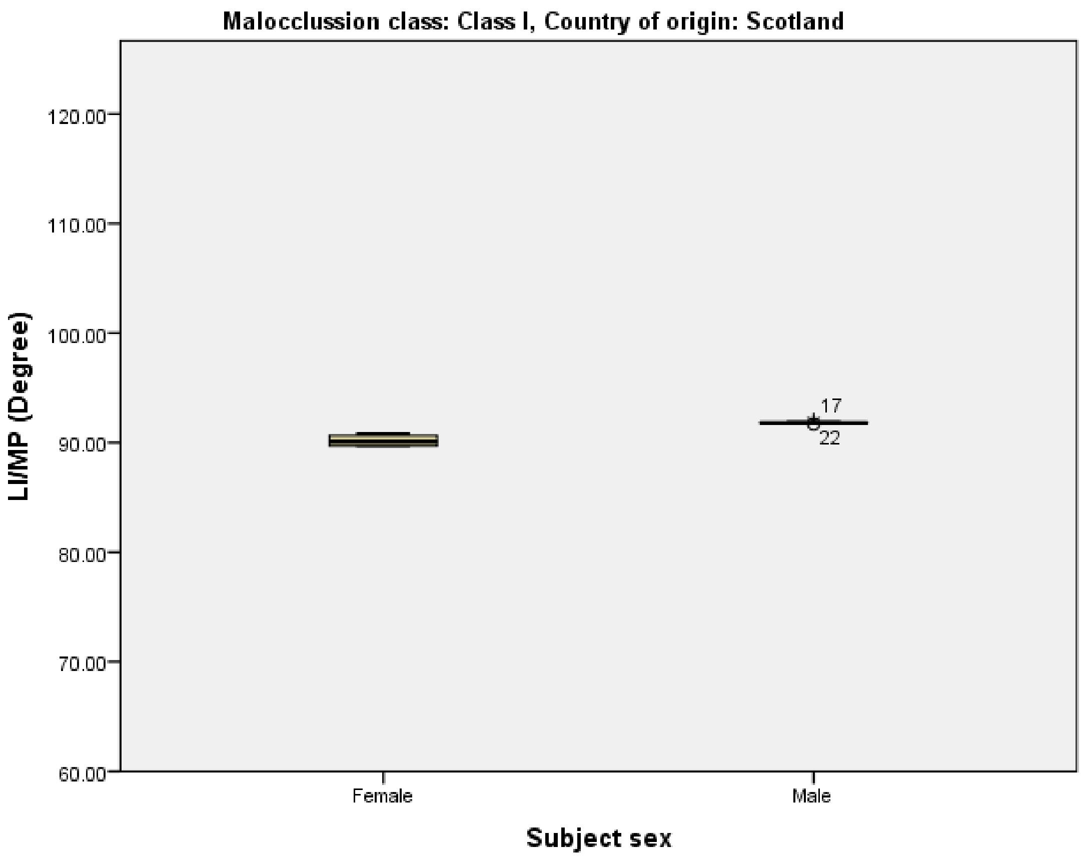
Female
Male
Subject sex


Malocclussion class: Class I, Country of origin: Jordan
LI/MP (Degree)
120.00
110.00
100.00
90.00
80.00
70.00
60.00
1
Female
Male
Subject sex


Malocclussion class: Class I, Country of origin: Scotland
LI/MP (Degree)
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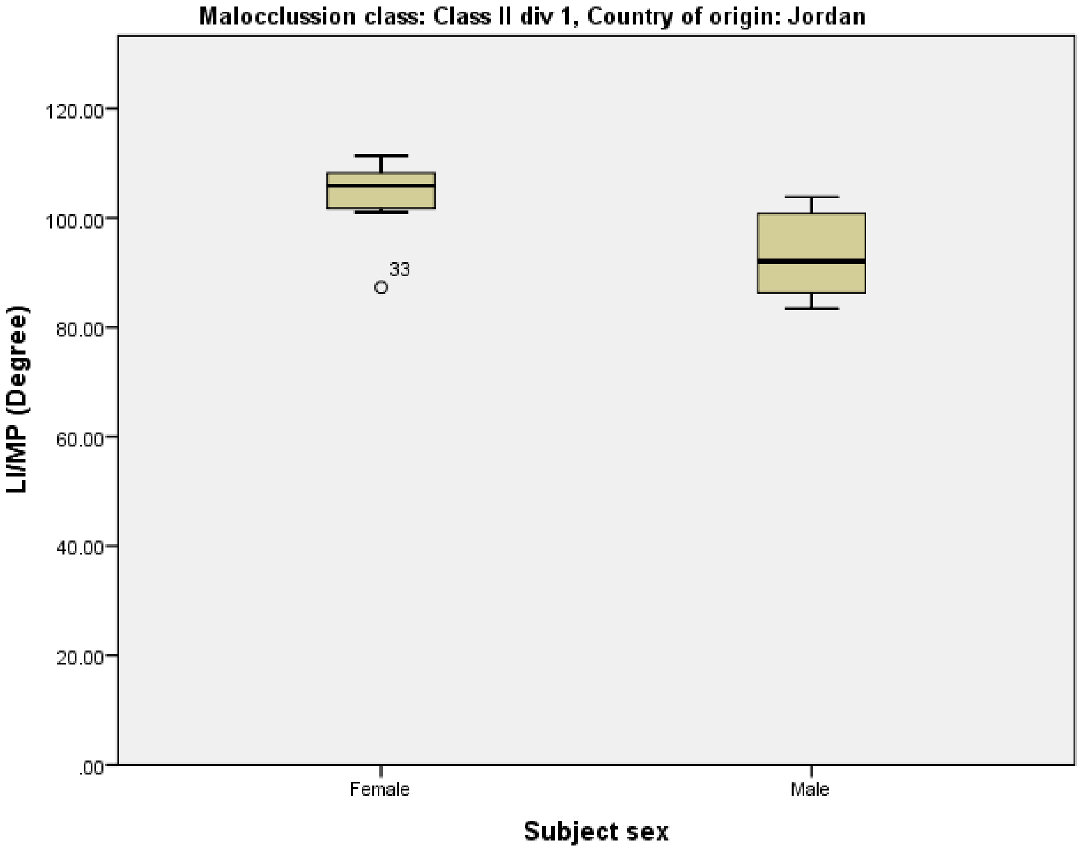
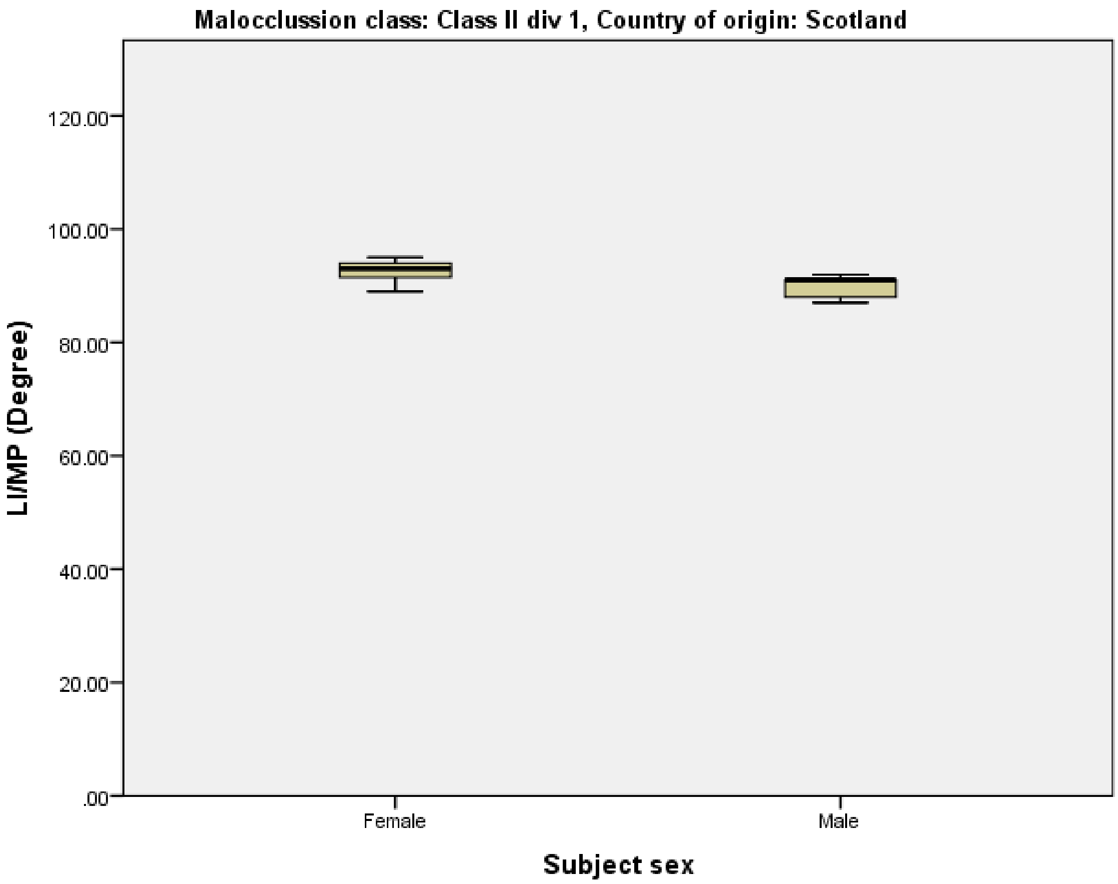
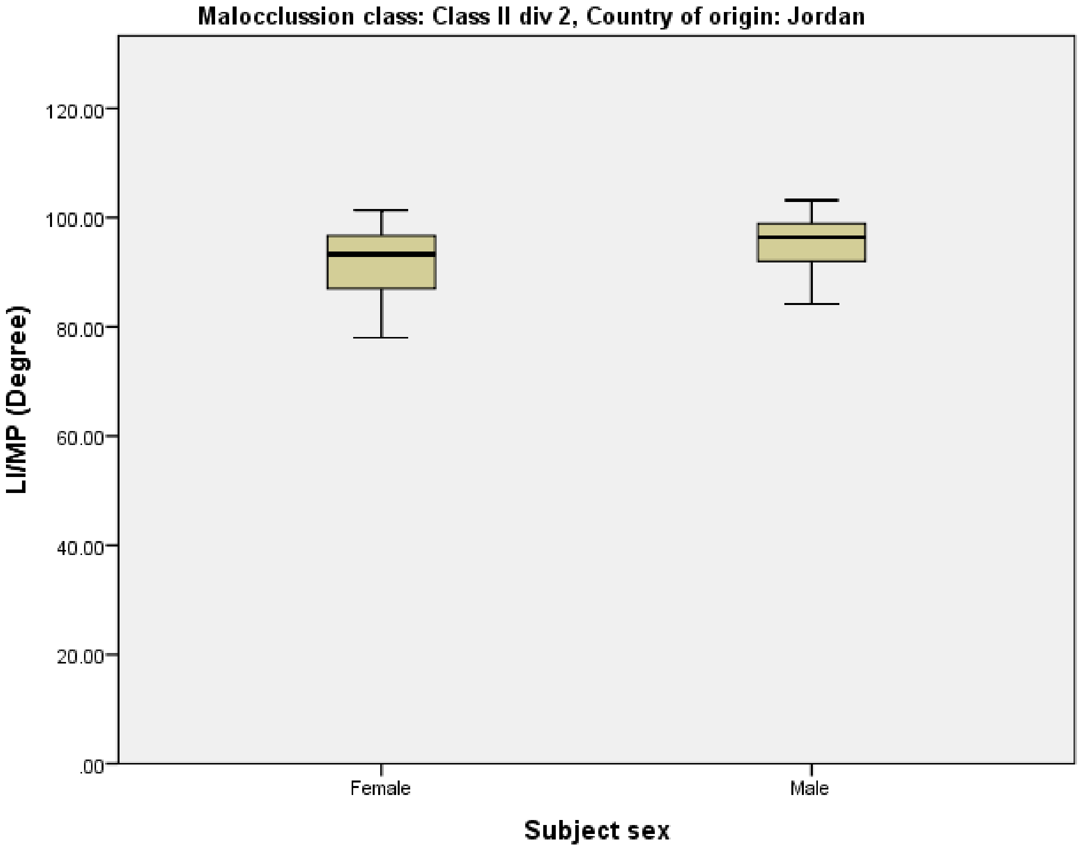
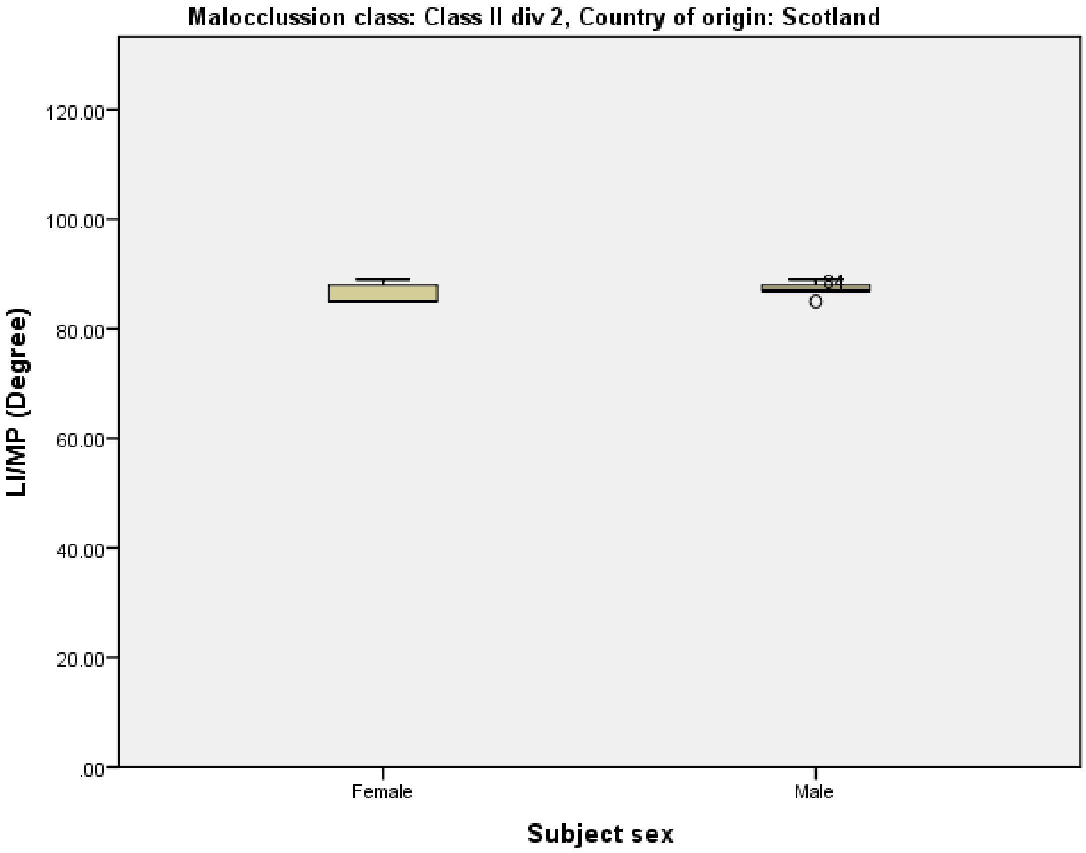
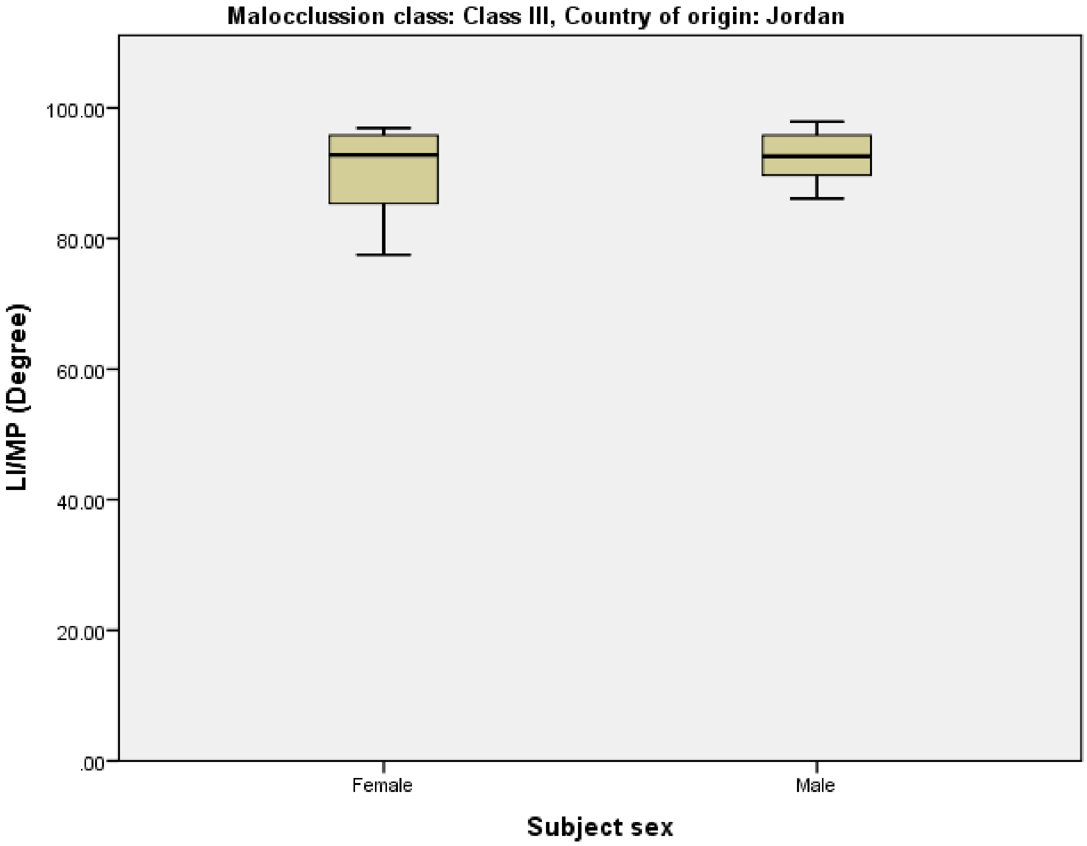
110.00
100.00
90.00
80.00
70.00
60.00
17
22
Female
Male
Subject sex

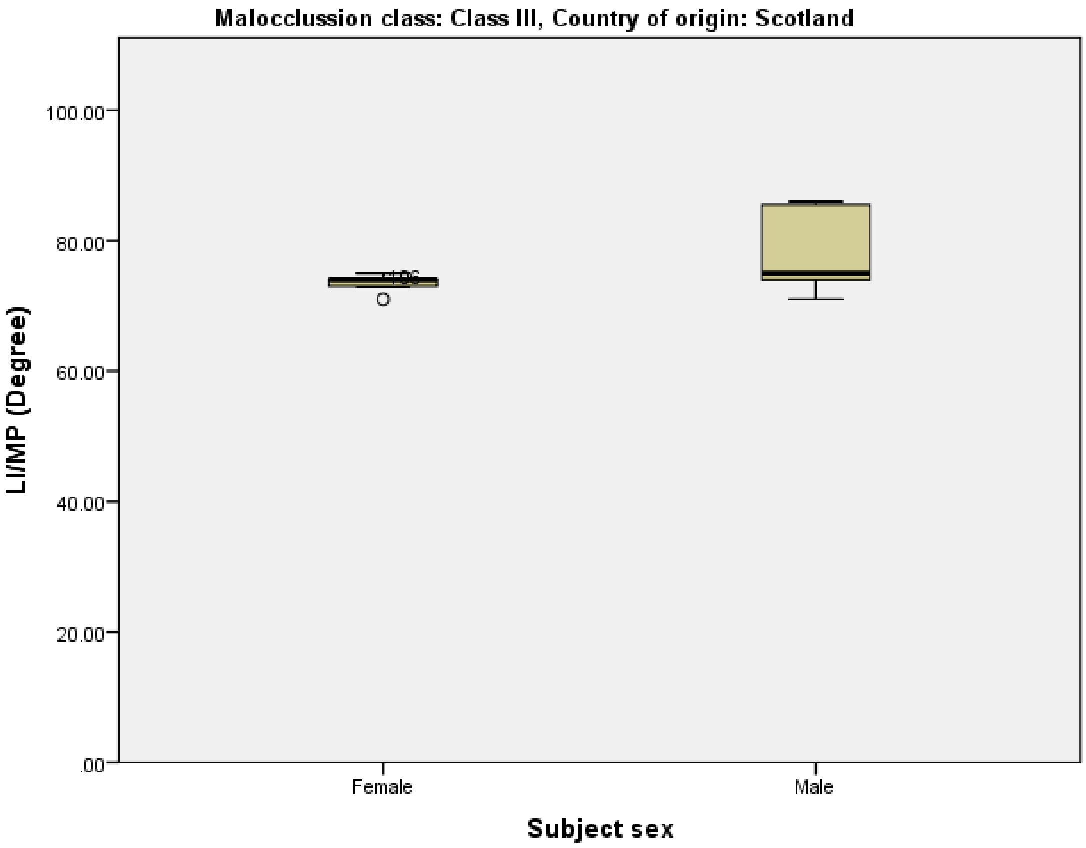

Malocclussion class: Class II div 1, Country of origin: Jordan
LI/MP (Degree)
120.00
100.00
80.00
60.00
40.00
20.00
.00
33
Female
Male
Subject sex

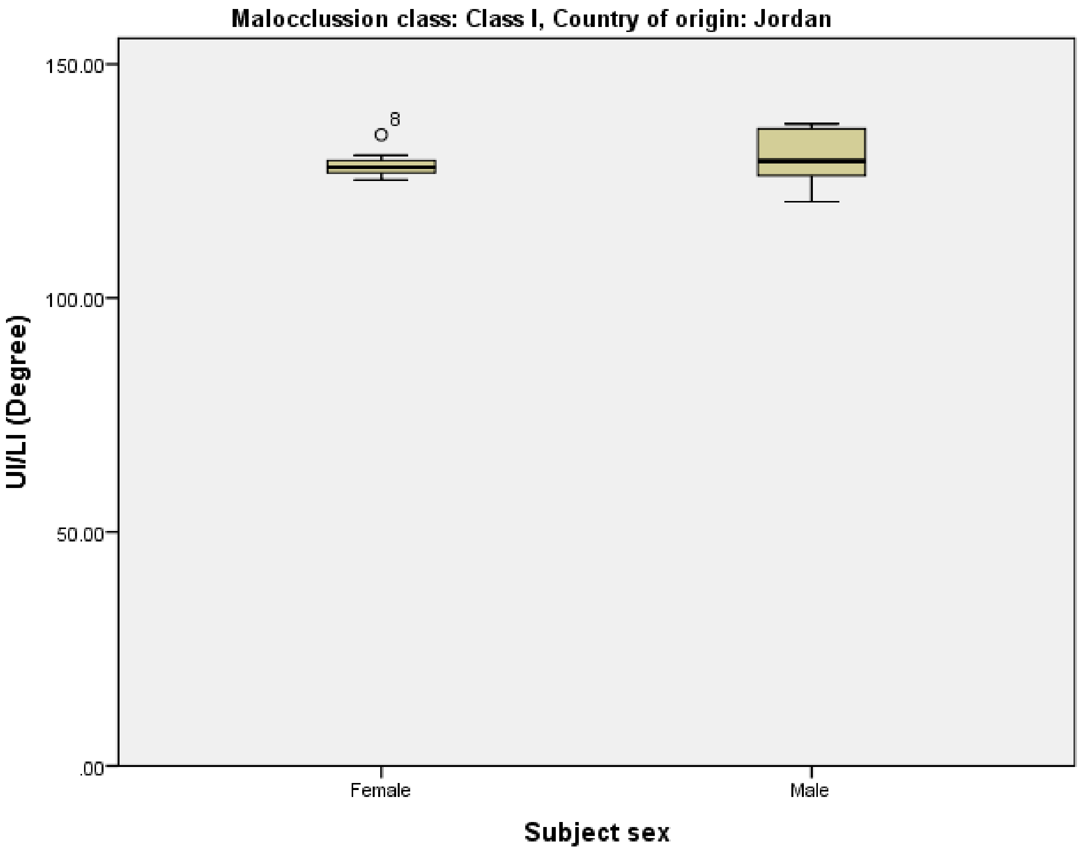

Malocclussion class: Class II div 1, Country of origin: Scotland
LI/MP (Degree)
120.00
100.00
80.00
60.00
40.00
20.00
.00
Female
Male
Subject sex

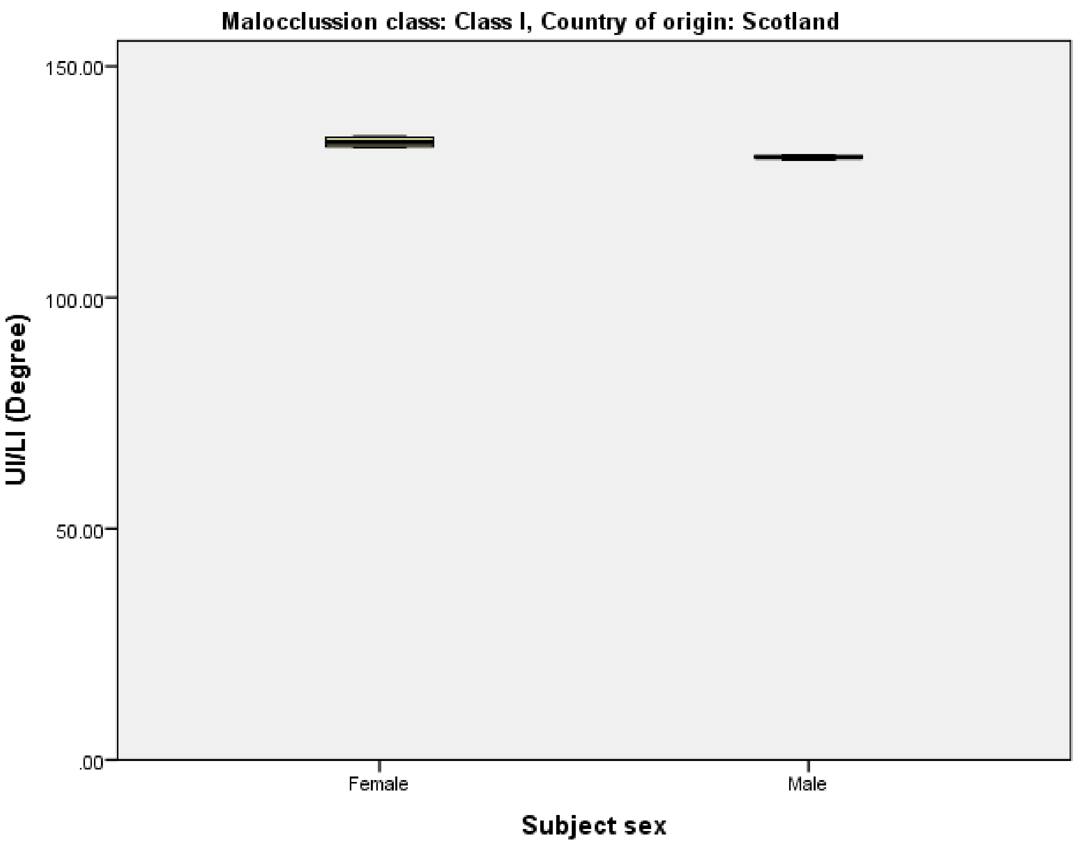

Malocclussion class: Class II div 2, Country of origin: Jordan
LI/MP (Degree)
120.00
100.00
80.00
60.00
40.00
20.00
.00
Female
Male
Subject sex

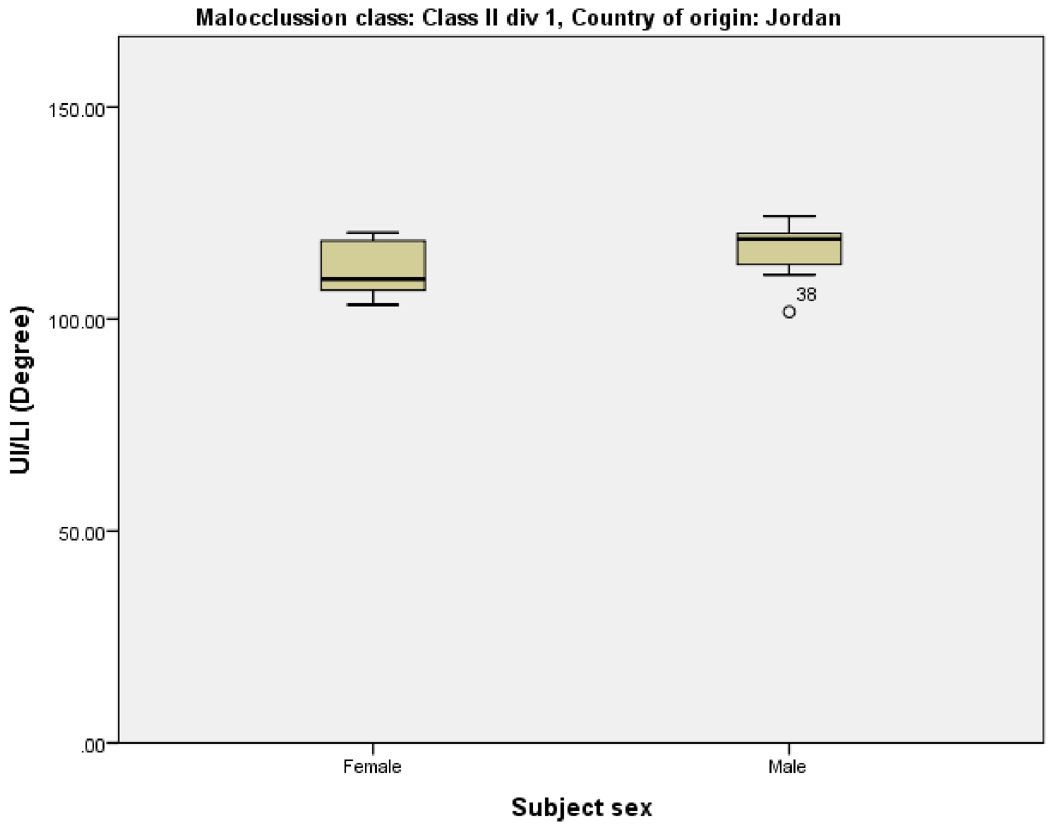

Malocclussion class: Class II div 2, Country of origin: Scotland
LI/MP (Degree)
120.00
100.00
80.00
60.00
40.00
20.00
.00
Female
Male
Subject sex


Malocclussion class: Class III, Country of origin: Jordan
LI/MP (Degree)
100.00
80.00
60.00
40.00
20.00
.00
Female
Male
Subject sex

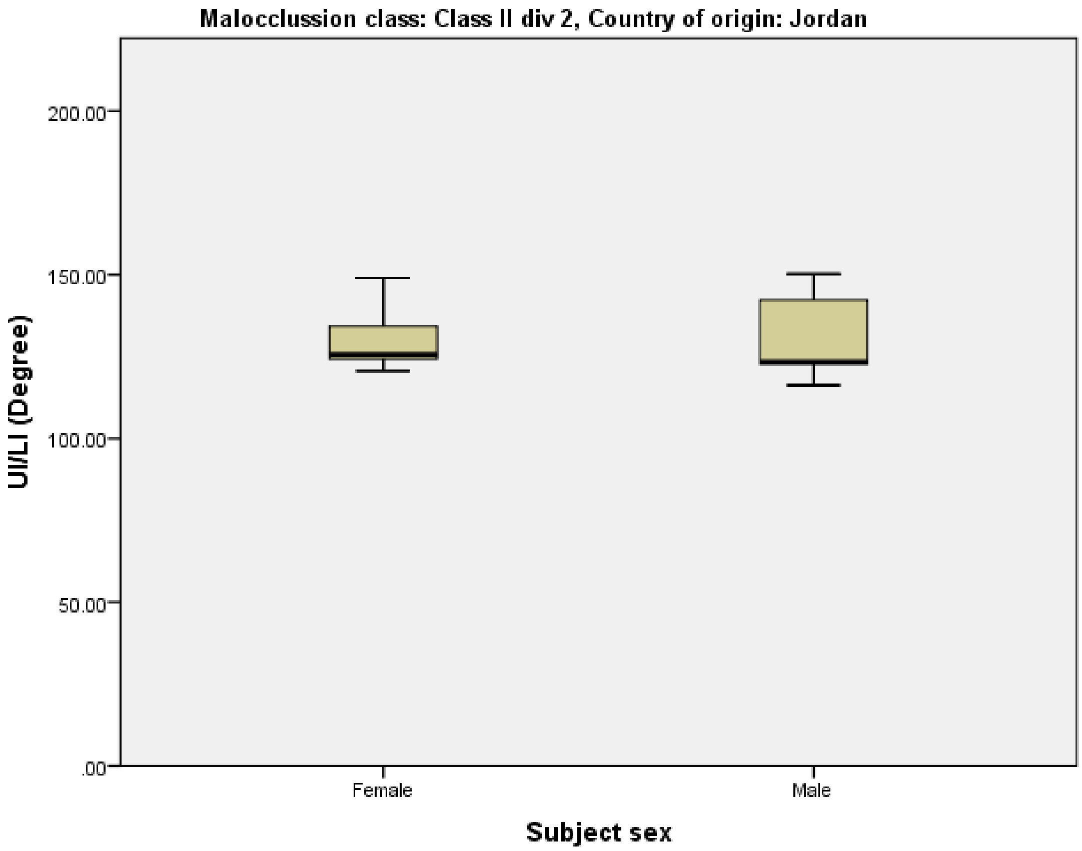

Malocclussion class: Class III, Country of origin: Scotland
LI/MP (Degree)
100.00
80.00
60.00
40.00
20.00
.00
Female
Male
Subject sex

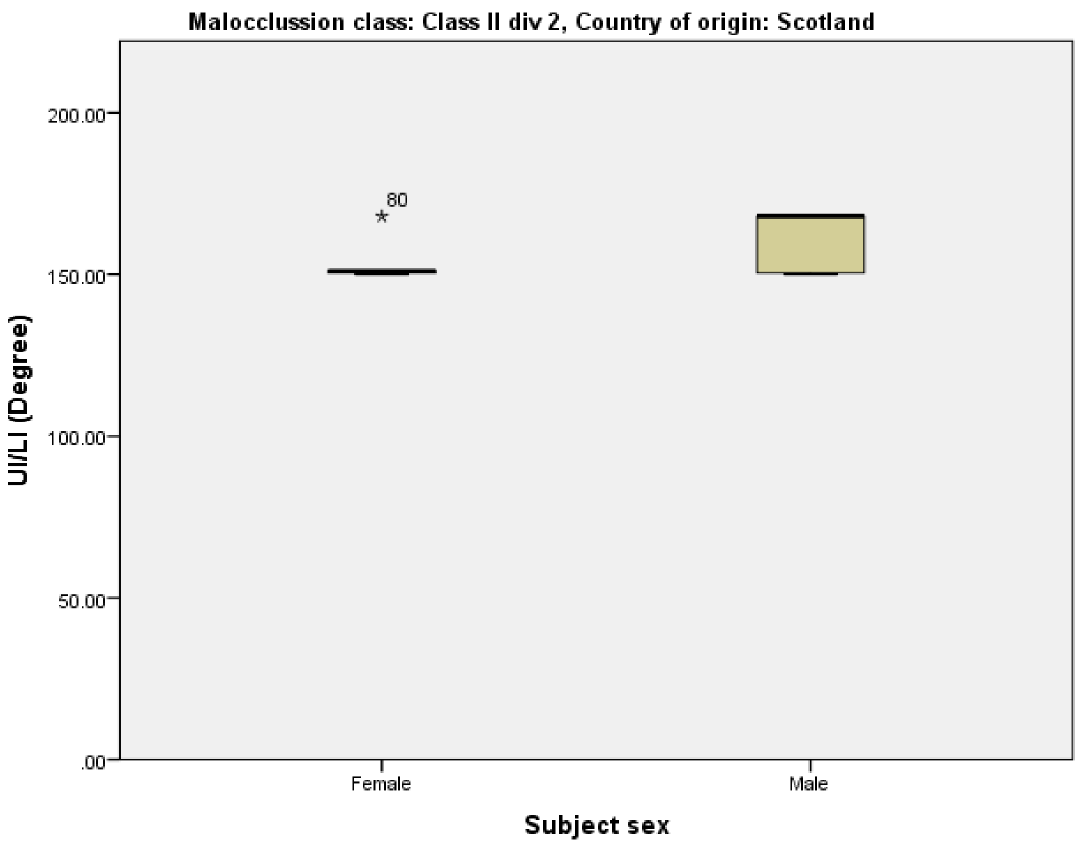

Malocclussion class: Class I, Country of origin: Jordan
UI/LI (Degree)
150.00
100.00
50.00
.00
8
Female
Male
Subject sex

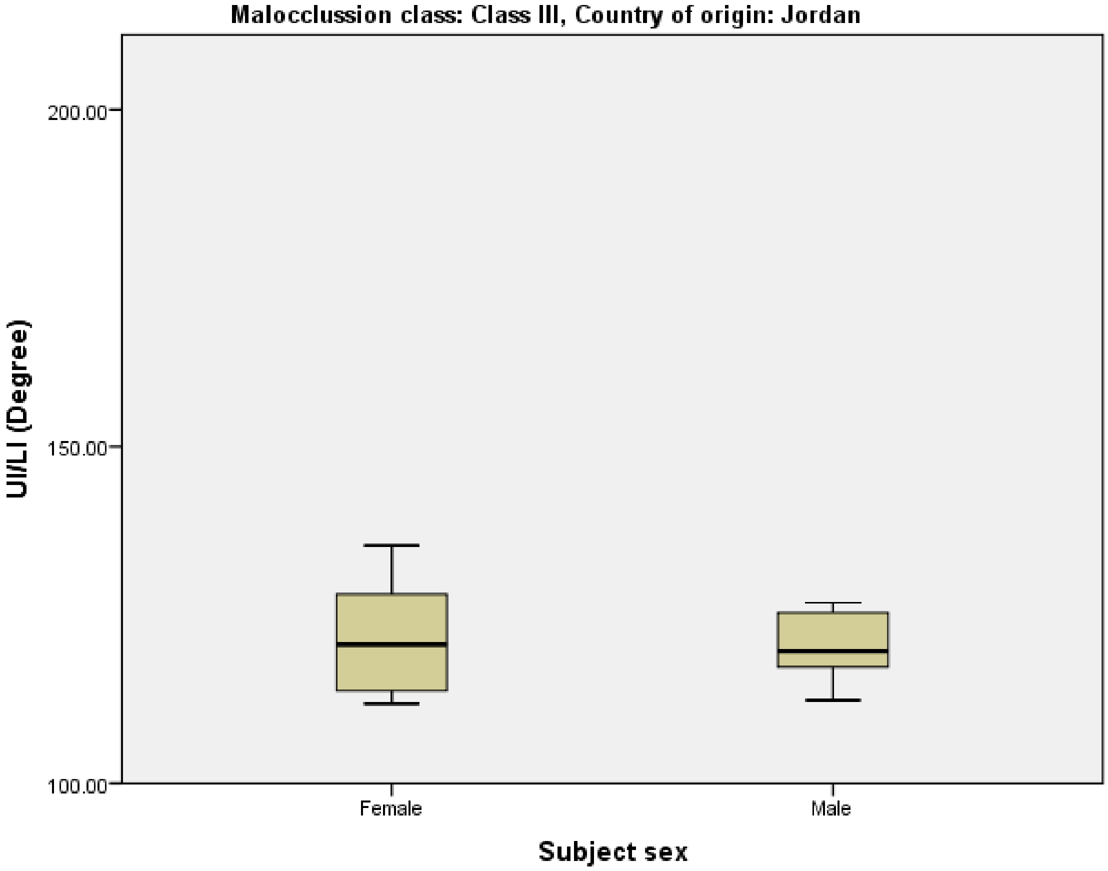

Malocclussion class: Class I, Country of origin: Scotland
UI/LI (Degree)
150.00
100.00
50.00
.00
Female
Male
Subject sex

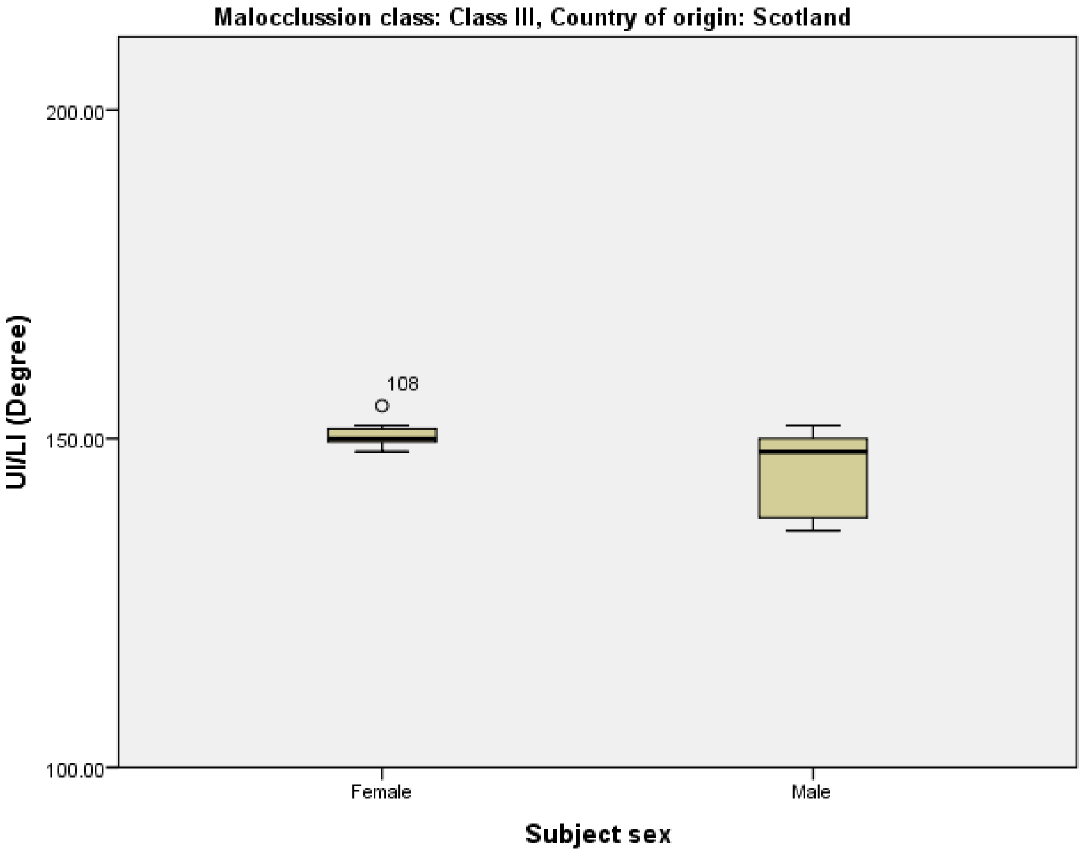

Malocclussion class: Class II div 1, Country of origin: Jordan
150.00
100.00
50.00
.00
UI/LI (Degree)
38
Female
Male
Subject sex

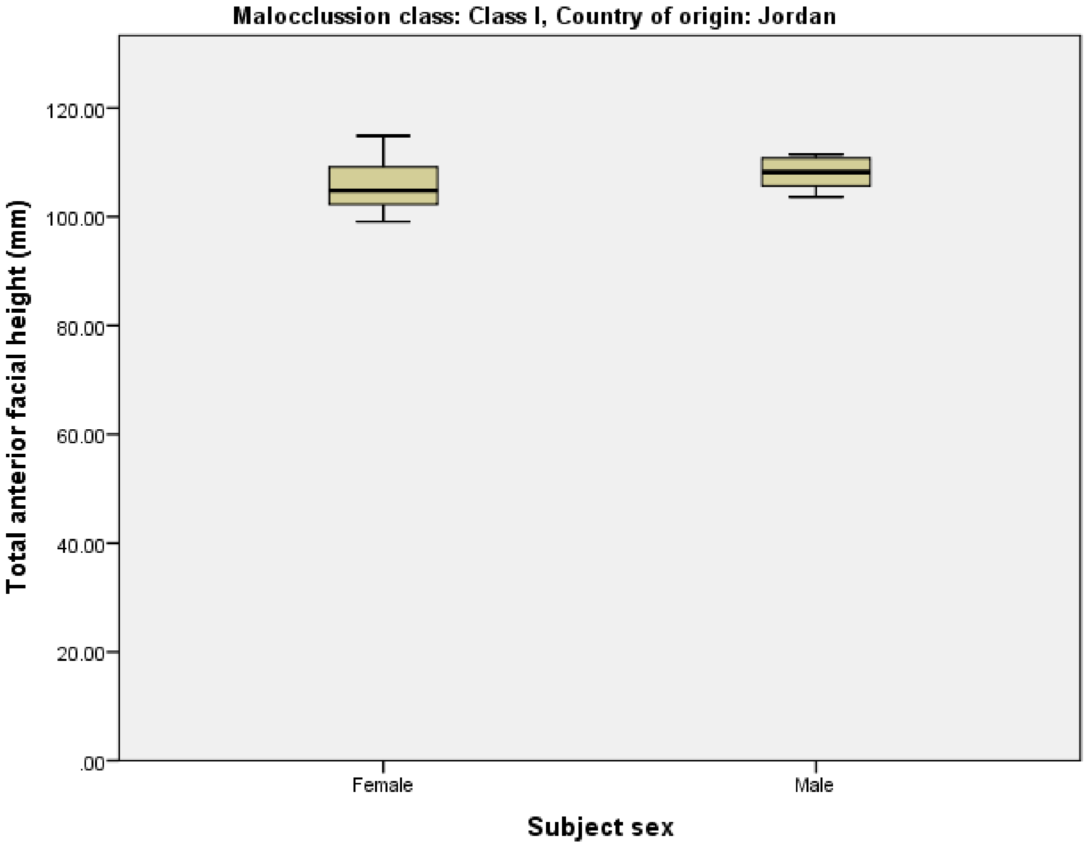

Malocclussion class: Class II div 1, Country of origin: Scotland
150.00
100.00
50.00
.00
UI/LI (Degree)
Female
Male
Subject sex

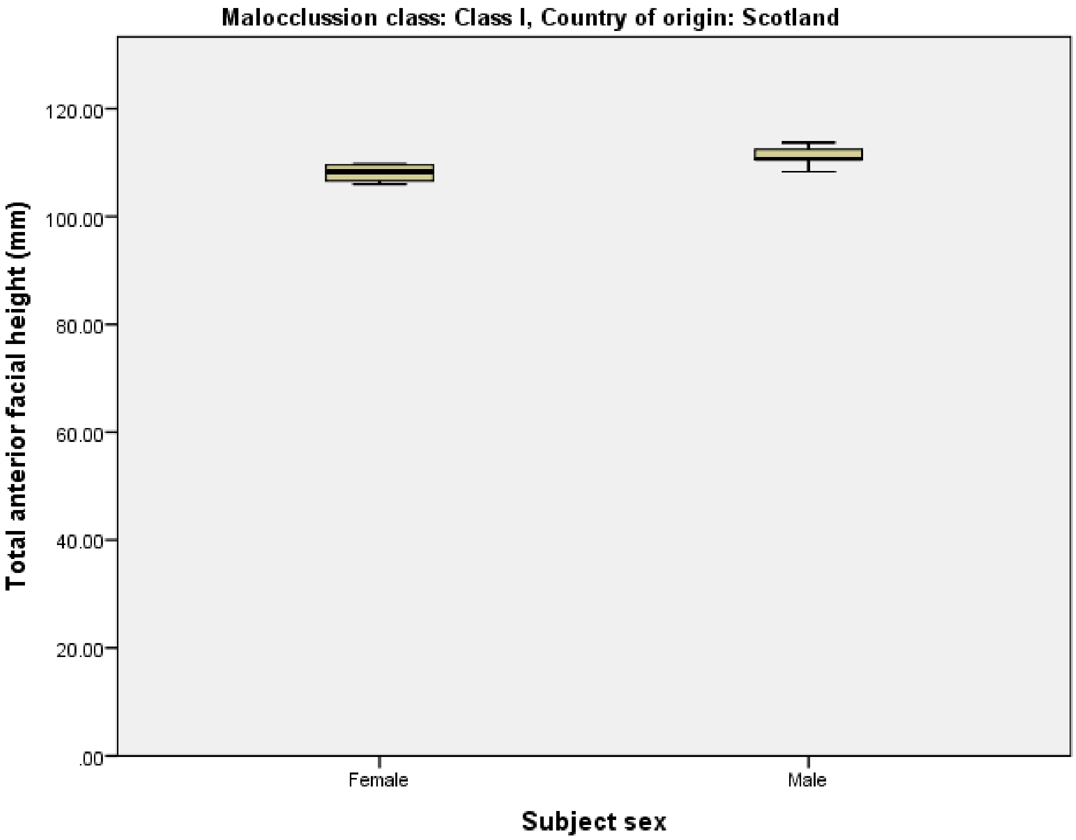

Malocclussion class: Class II div 2, Country of origin: Jordan
UI/LI (Degree)
200.00
150.00
100.00
50.00
.00
Female
Male
Subject sex

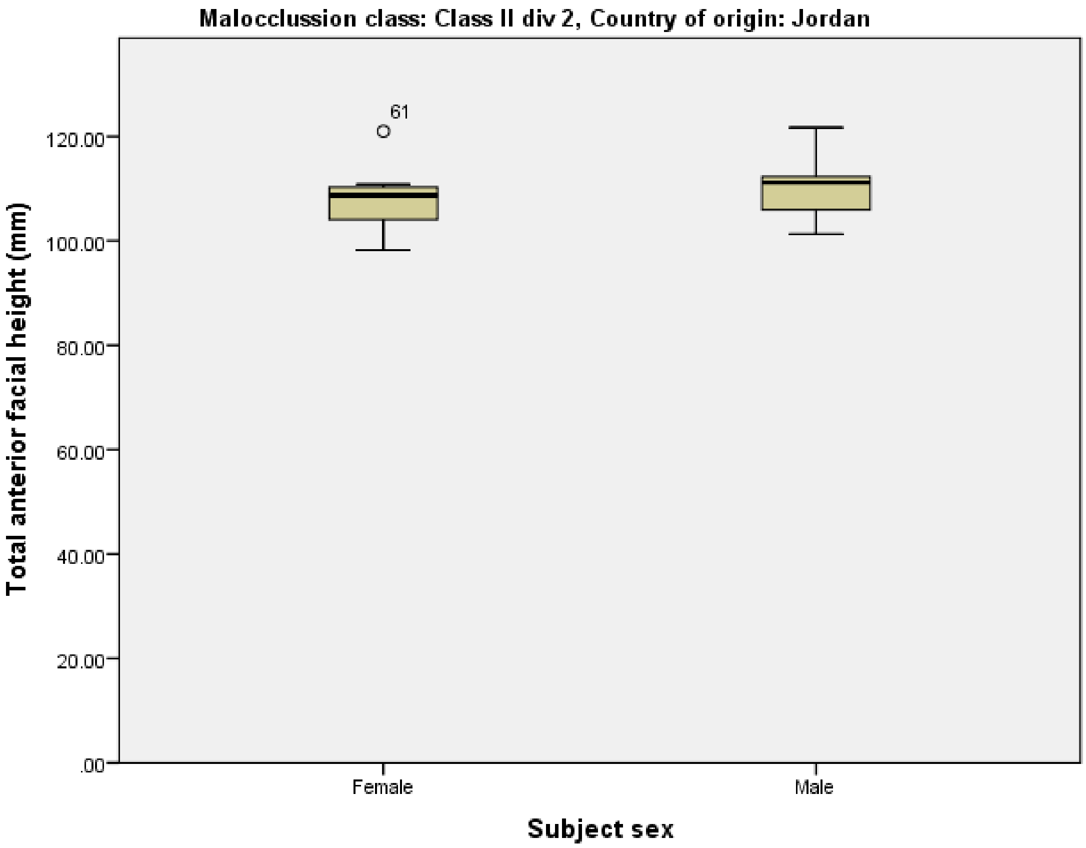

Malocclussion class: Class II div 2, Country of origin: Scotland
UI/LI (Degree)
200.00
150.00
100.00
50.00
.00
80
Female
Male
Subject sex

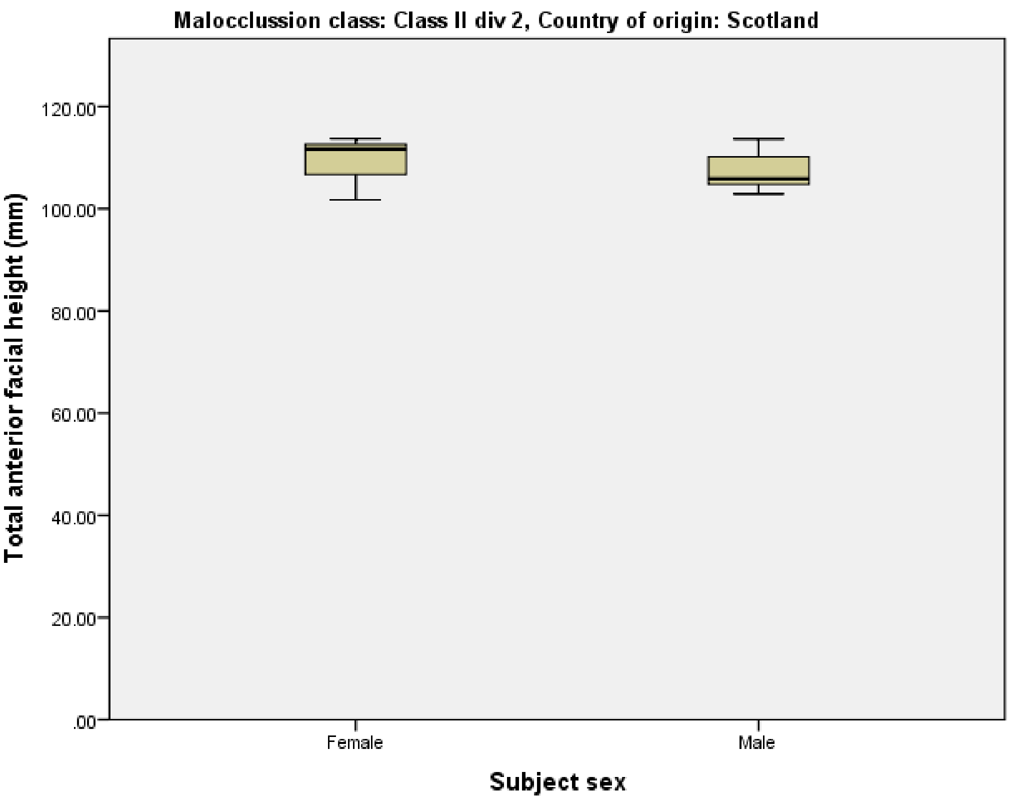

Malocclussion class: Class III, Country of origin: Jordan
200.00
150.00
100.00
UI/LI (Degree)
Female
Male
Subject sex

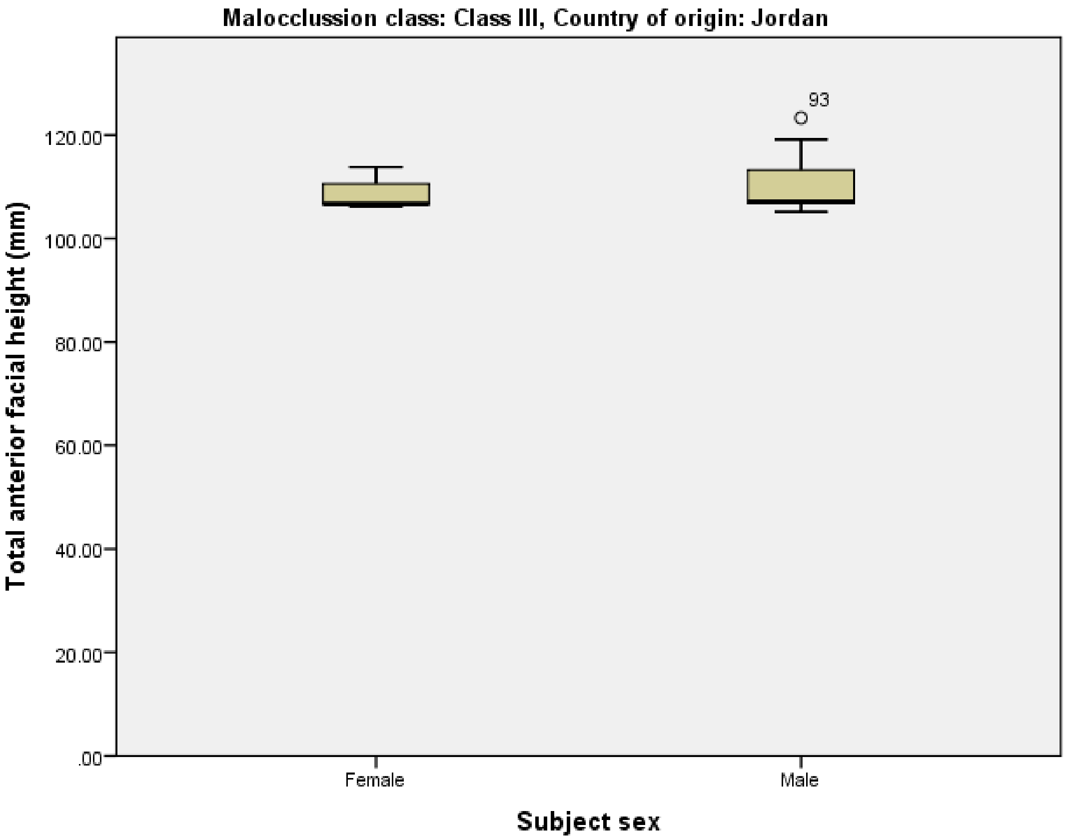

Malocclussion class: Class III, Country of origin: Scotland
200.00
150.00
100.00
UI/LI (Degree)
108
Female
Male
Subject sex

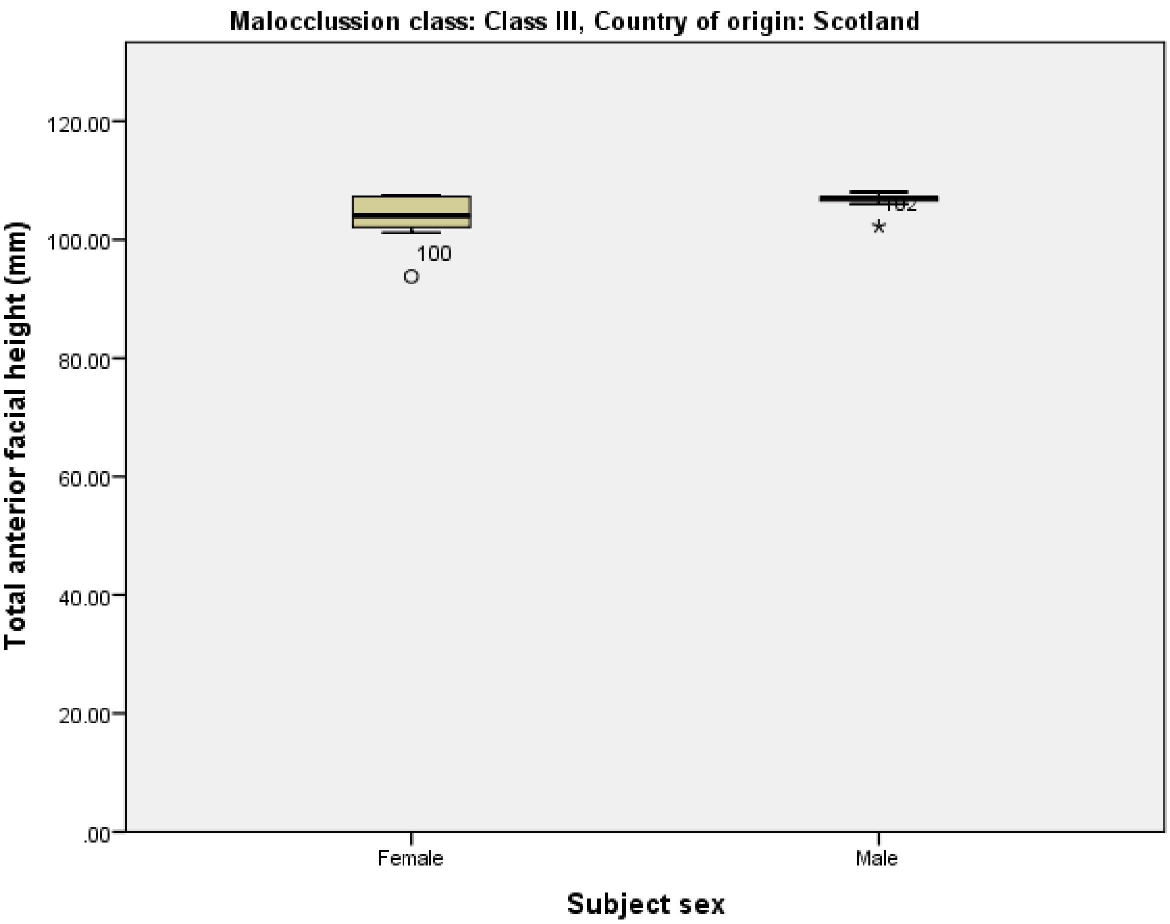

Malocclussion class: Class I, Country of origin: Jordan
Total anterior facial height (mm)
120.00
100.00
80.00
60.00
40.00
20.00
.00
Female
Male
Subject sex

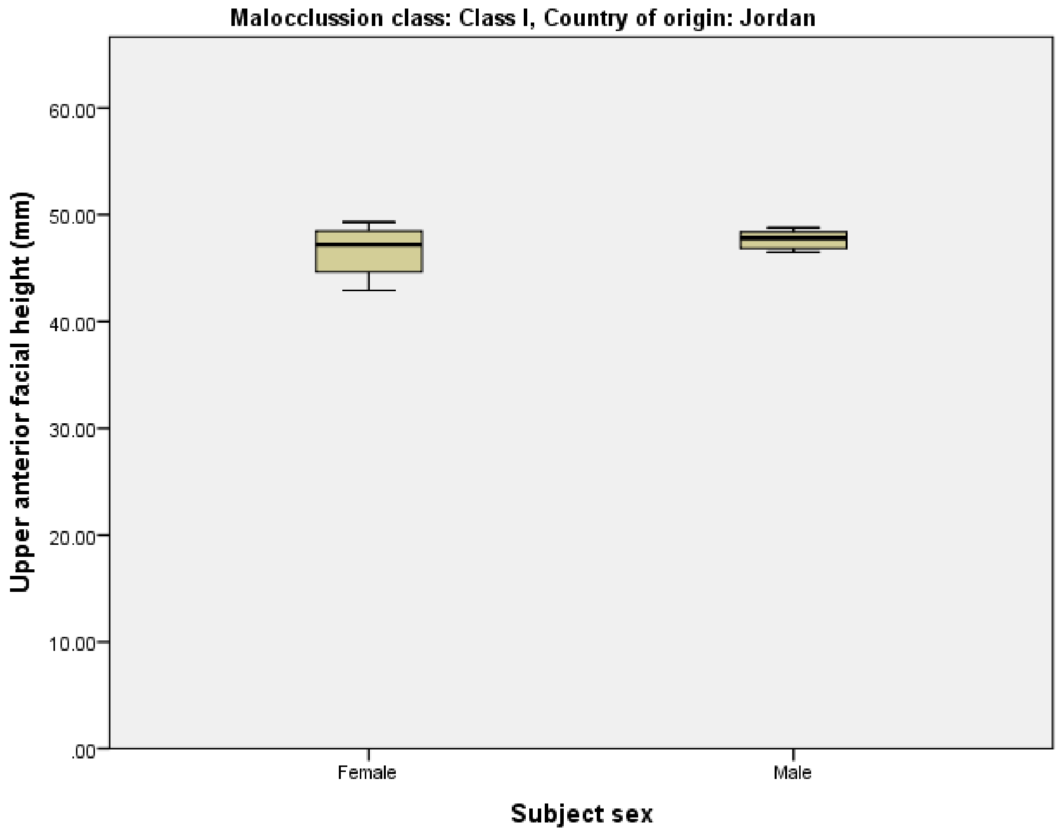

Malocclussion class: Class I, Country of origin: Scotland
Total anterior facial height (mm)
120.00
100.00
80.00
60.00
40.00
20.00
.00
Female
Male
Subject sex

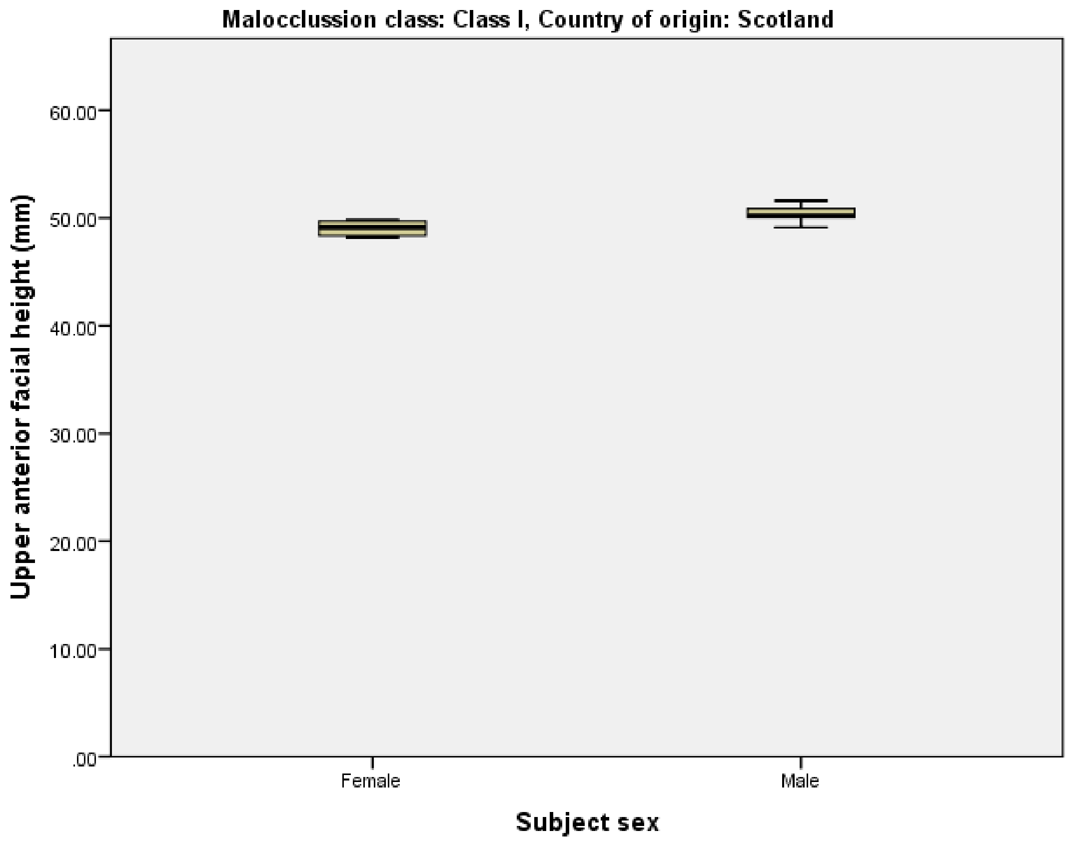

Malocclussion class: Class II div 2, Country of origin: Jordan
Total anterior facial height (mm)
120.00
100.00
80.00
60.00
40.00
20.00
.00
61
Female
Male
Subject sex

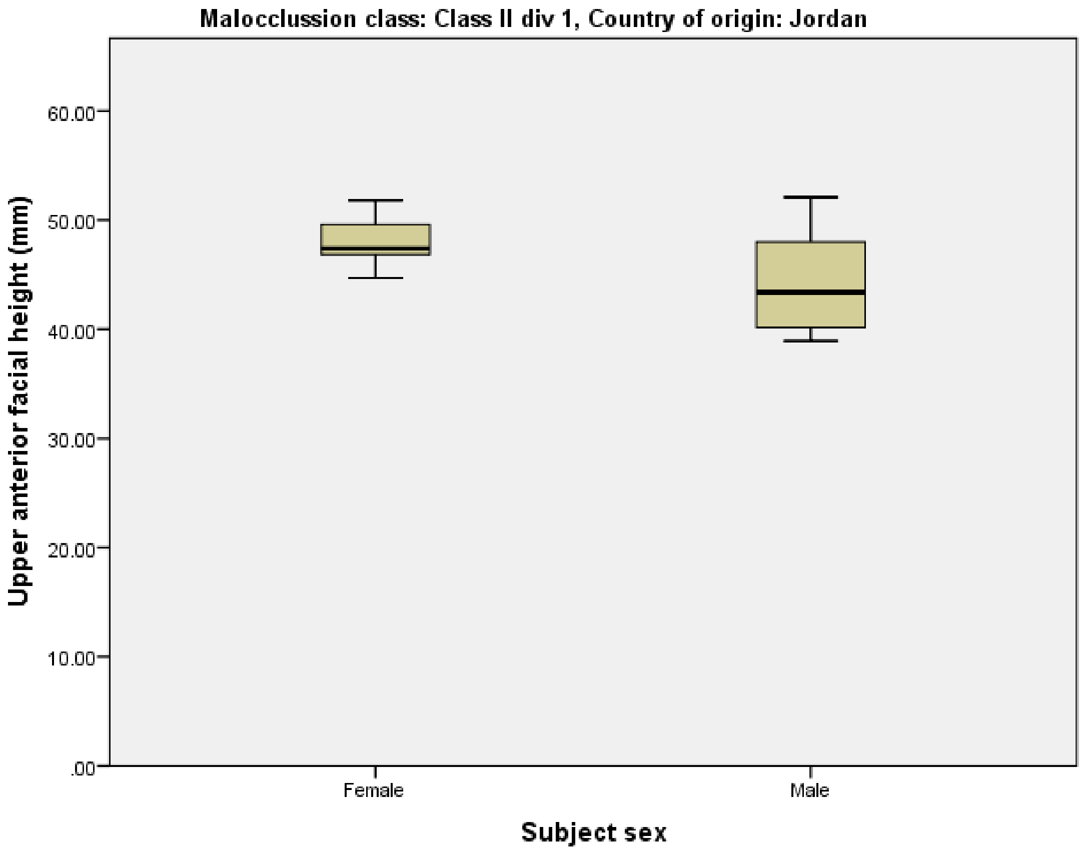

Malocclussion class: Class II div 2, Country of origin: Scotland
Total anterior facial height (mm)
120.00
100.00
80.00
60.00
40.00
20.00
.00
Female
Male
Subject sex

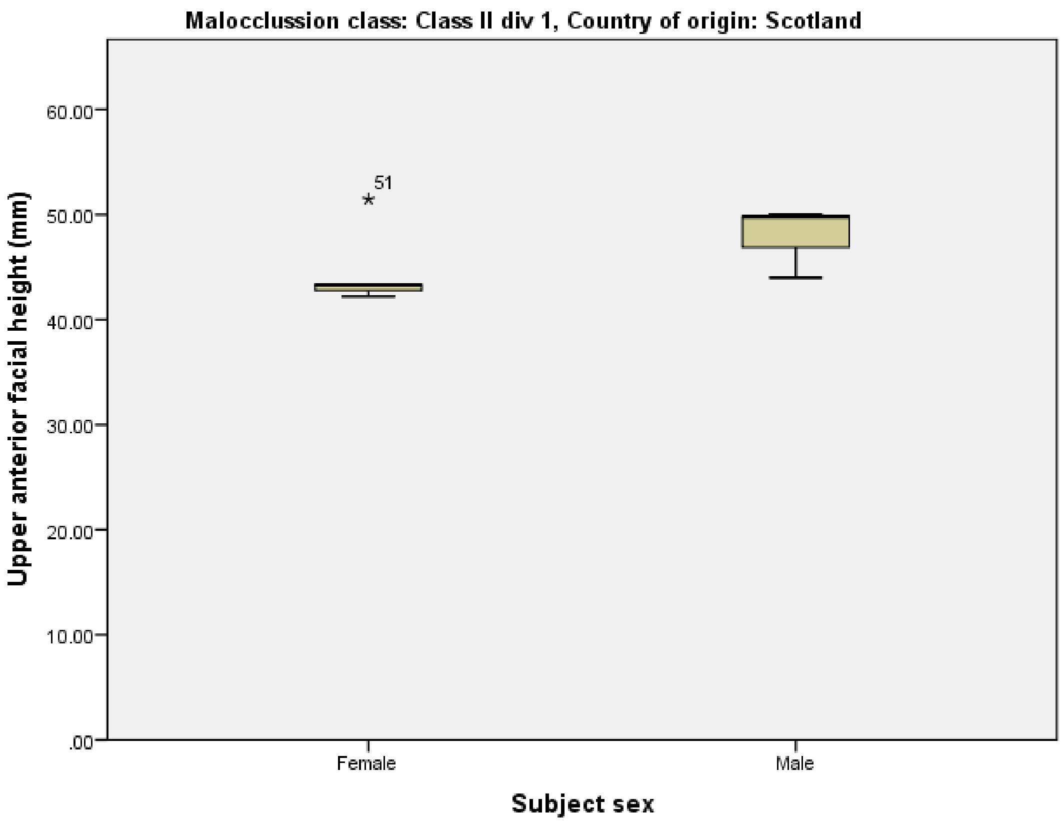

Malocclussion class: Class III, Country of origin: Jordan
Total anterior facial height (mm)
120.00
100.00
80.00
60.00
40.00
20.00
.00
93
Female
Male
Subject sex

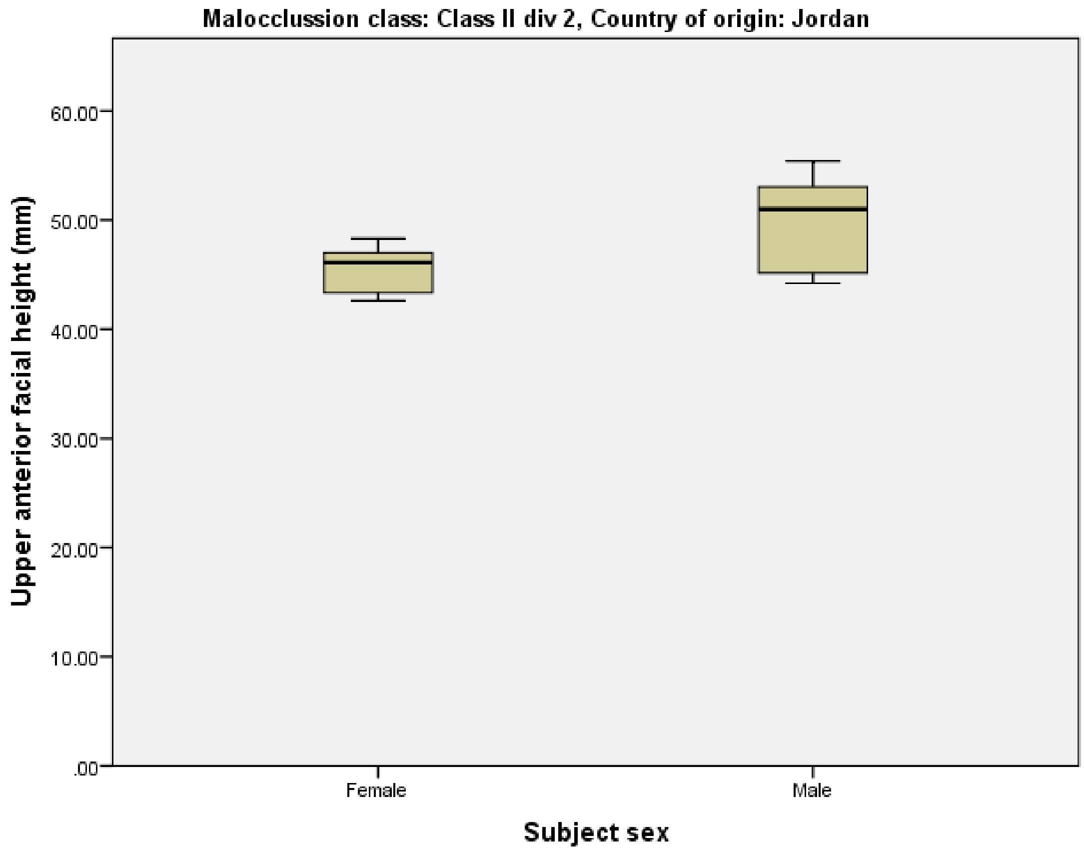

Malocclussion class: Class III, Country of origin: Scotland
Total anterior facial height (mm)
120.00
100.00
80.00
60.00
40.00
20.00
.00
100
Female
Male
Subject sex

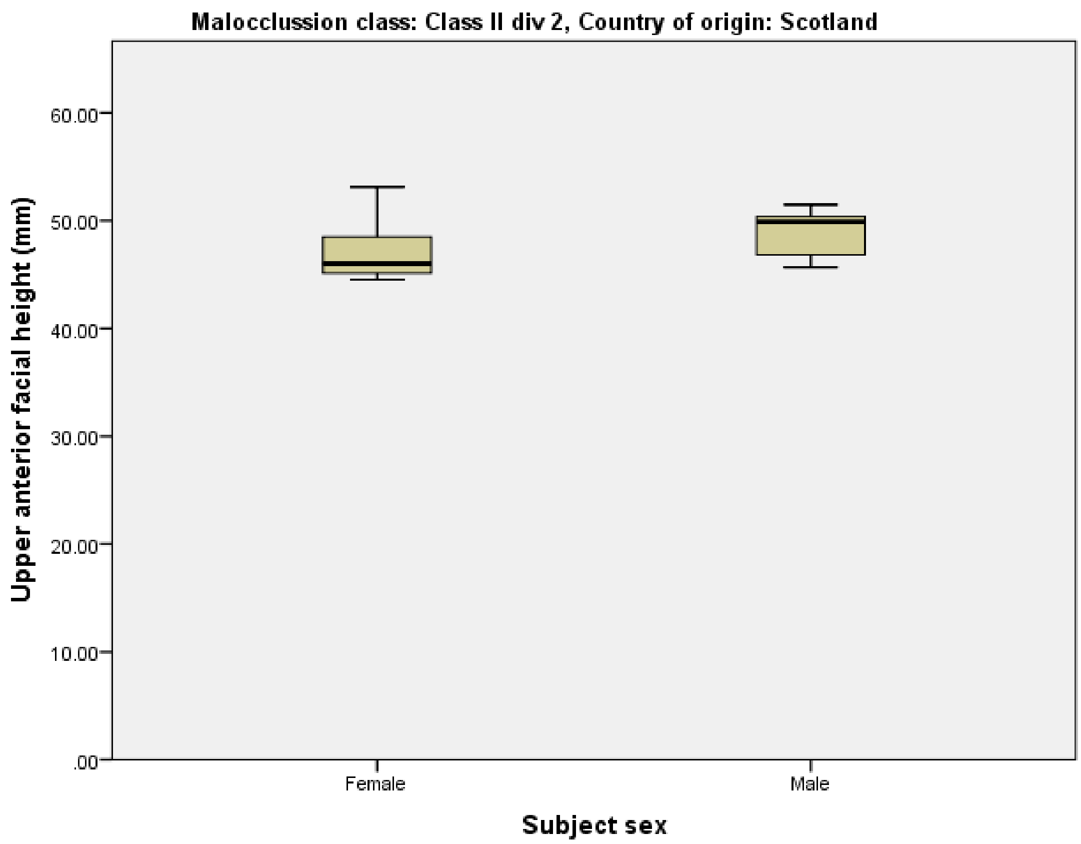

Malocclussion class: Class I, Country of origin: Jordan
Upper anterior facial height (mm)
60.00
50.00
40.00
30.00
20.00
10.00
.00
Female
Male
Subject sex

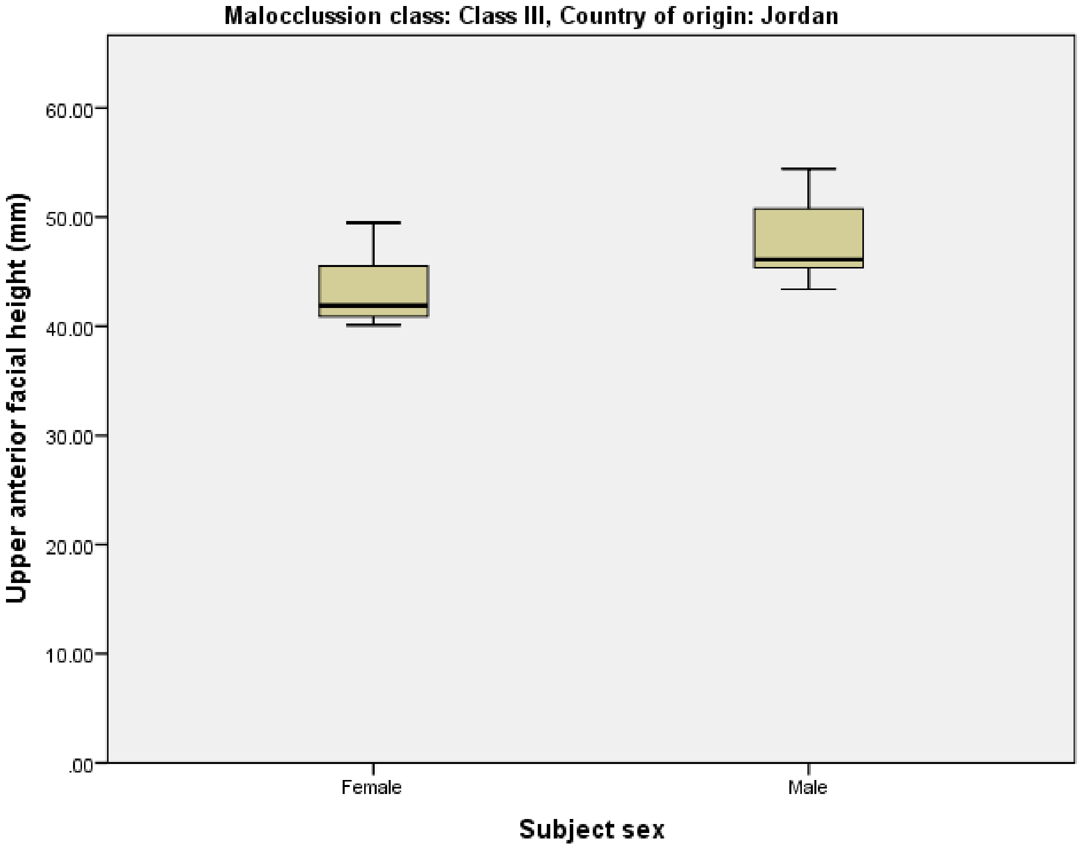

Malocclussion class: Class I, Country of origin: Scotland
Upper anterior facial height (mm)
60.00
50.00
40.00
30.00
20.00
10.00
.00
Female
Male
Subject sex

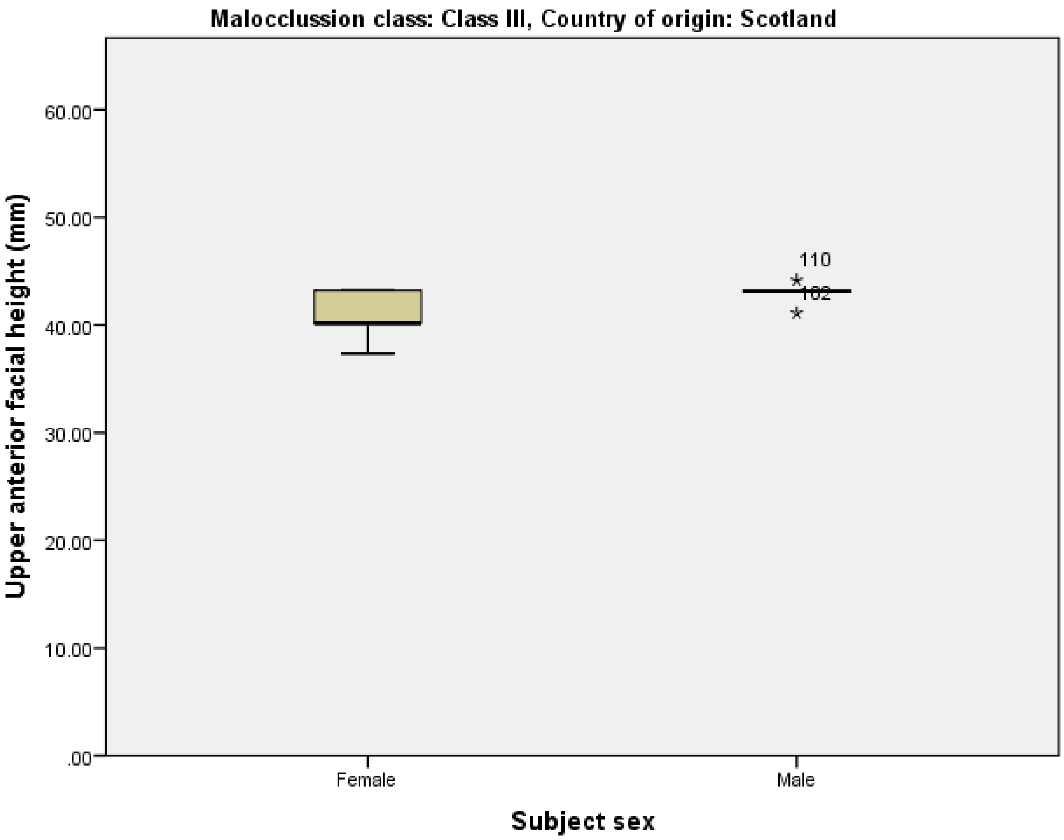

Malocclussion class: Class II div 1, Country of origin: Jordan
Upper anterior facial height (mm)
60.00
50.00
40.00
30.00
20.00
10.00
.00
Female
Male
Subject sex

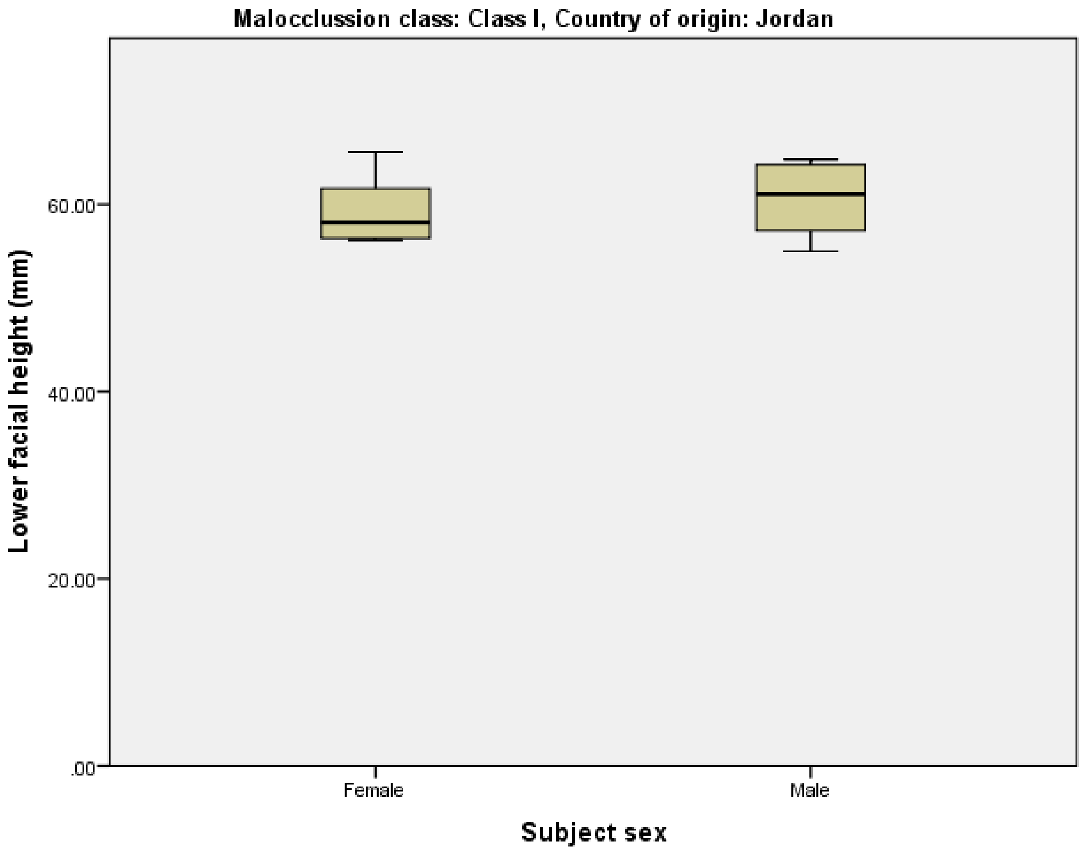

Malocclussion class: Class II div 1, Country of origin: Scotland
Upper anterior facial height (mm)
60.00
50.00
40.00
30.00
20.00
10.00
.00
51
Female
Male
Subject sex

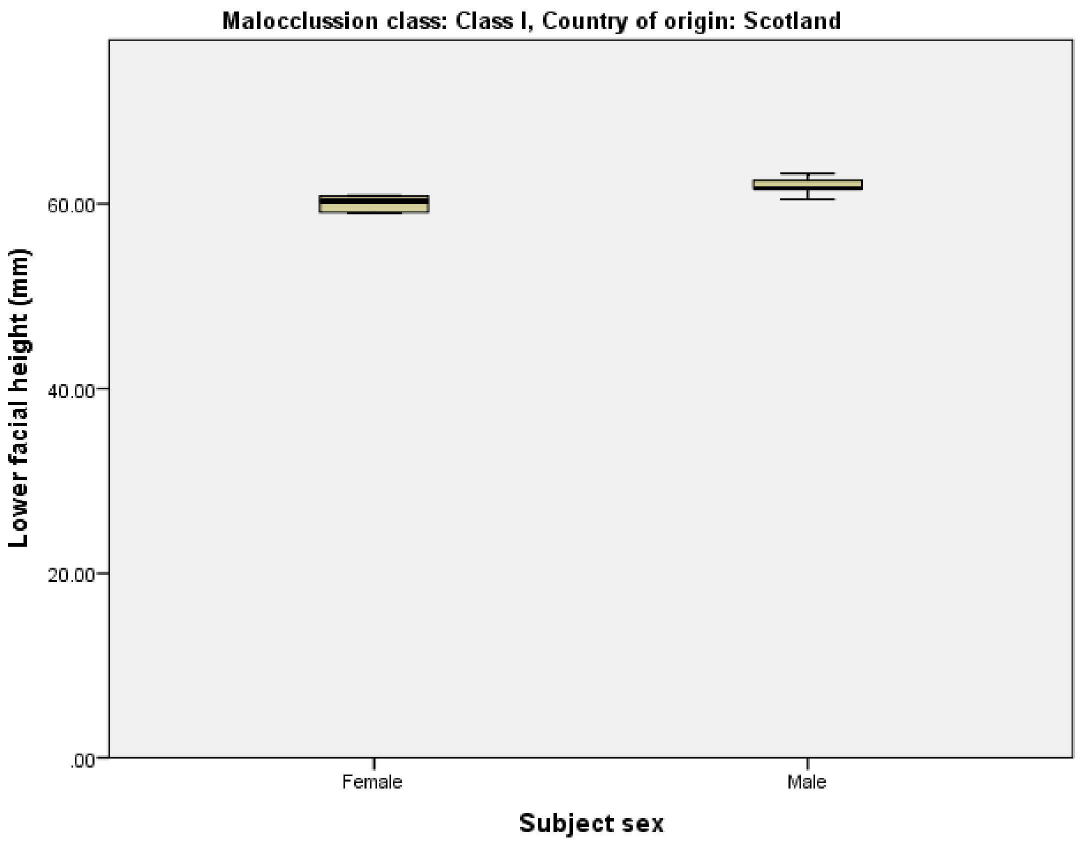

Malocclussion class: Class II div 2, Country of origin: Jordan
60.00
50.00
40.00
30.00
20.00
10.00
.00
Upper anterior facial height (mm)
Female
Male
Subject sex

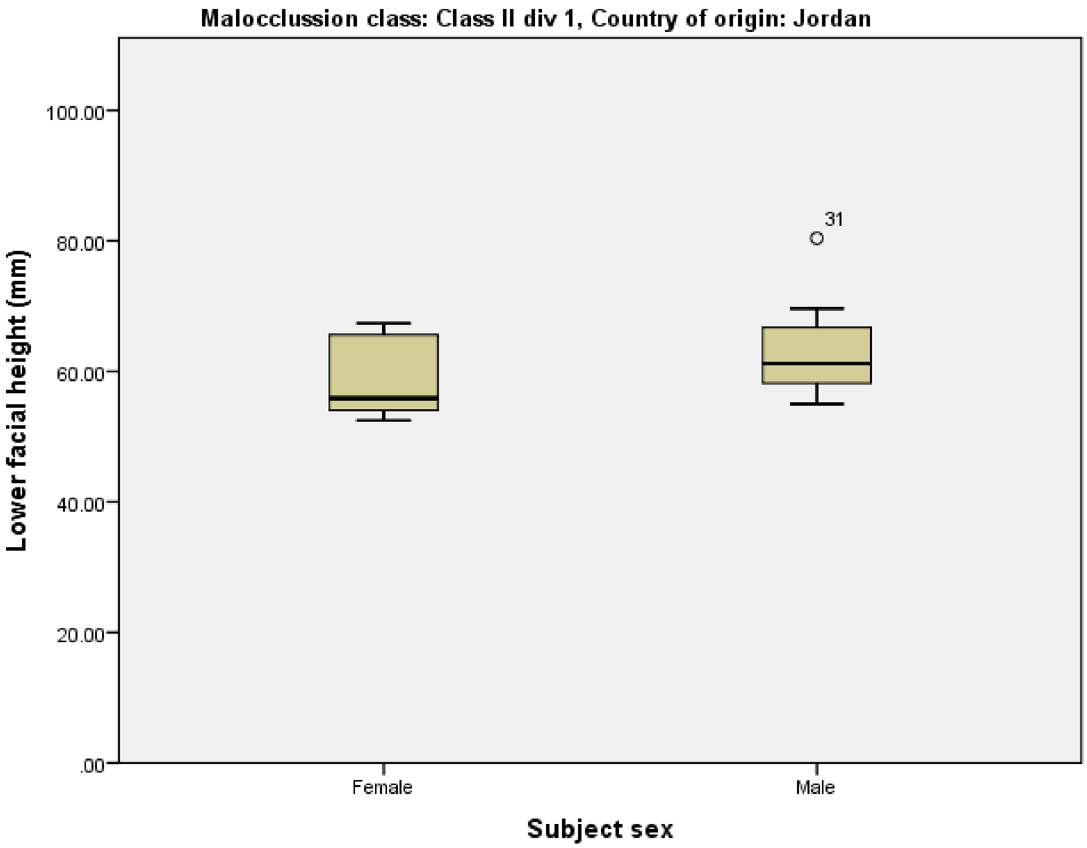

Malocclussion class: Class II div 2, Country of origin: Scotland
60.00
50.00
40.00
30.00
20.00
10.00
.00
Upper anterior facial height (mm)
Female
Male
Subject sex

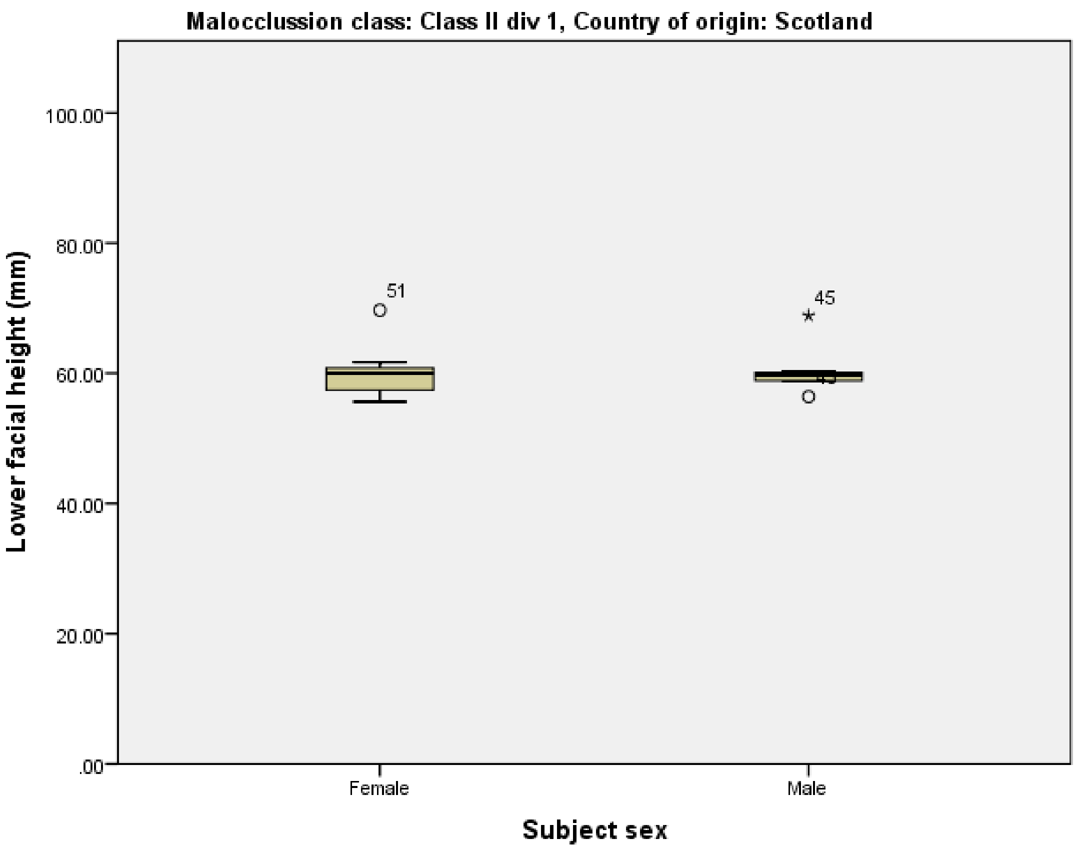

Malocclussion class: Class III, Country of origin: Jordan
Upper anterior facial height (mm)
60.00
50.00
40.00
30.00
20.00
10.00
.00
Female
Male
Subject sex

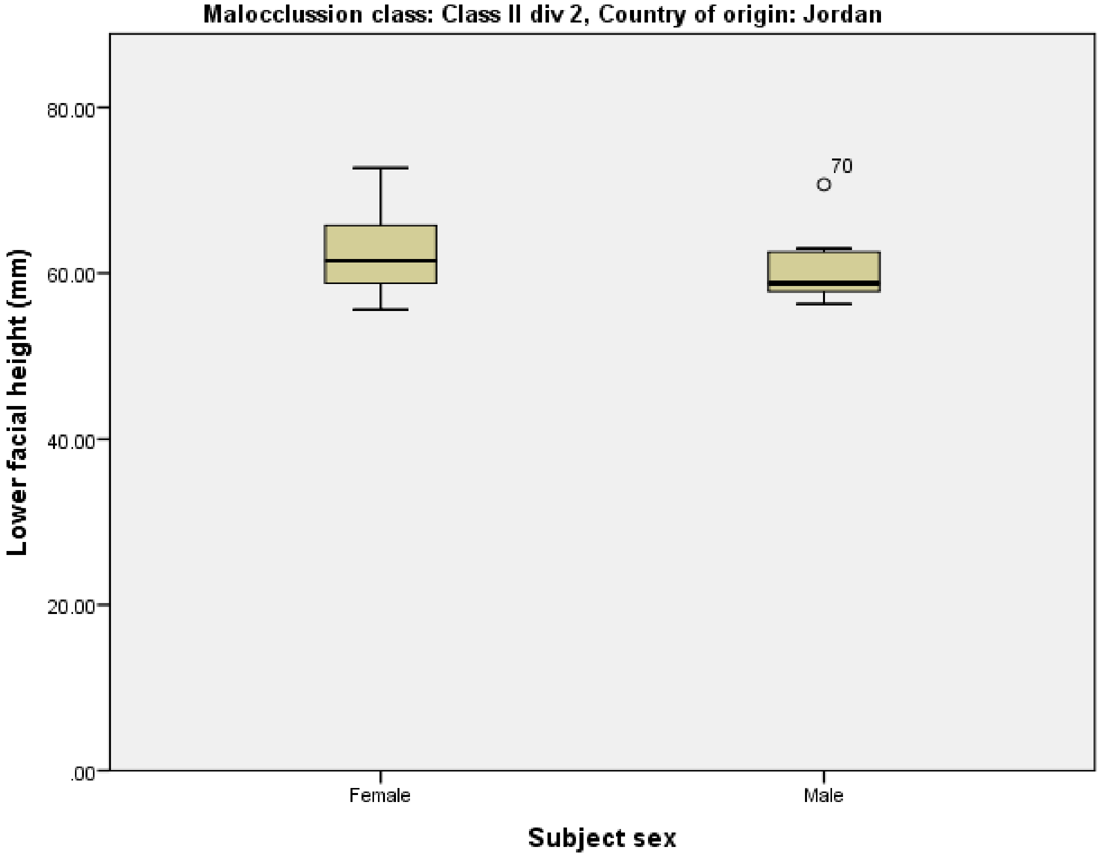

Malocclussion class: Class III, Country of origin: Scotland
Upper anterior facial height (mm)
60.00
50.00
40.00
30.00
20.00
10.00
.00
110
102
Female
Male
Subject sex

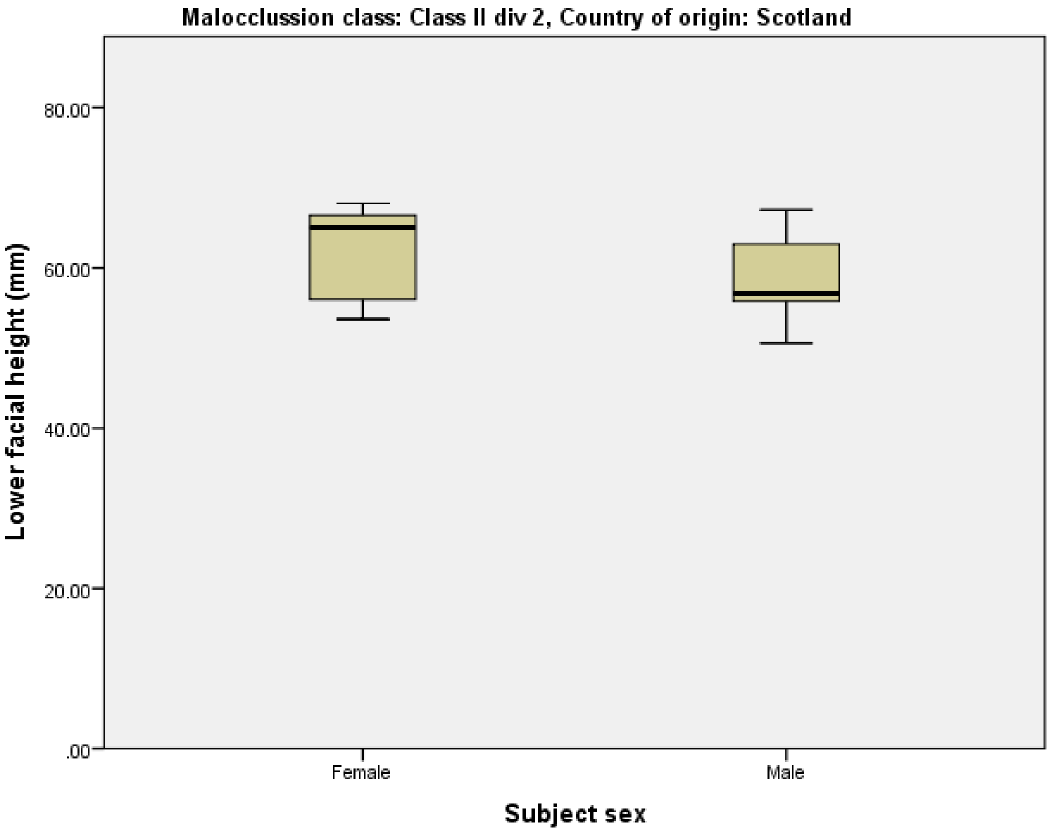

Malocclussion class: Class I, Country of origin: Jordan
Lower facial height (mm)
60.00
40.00
20.00
.00
Female
Male
Subject sex

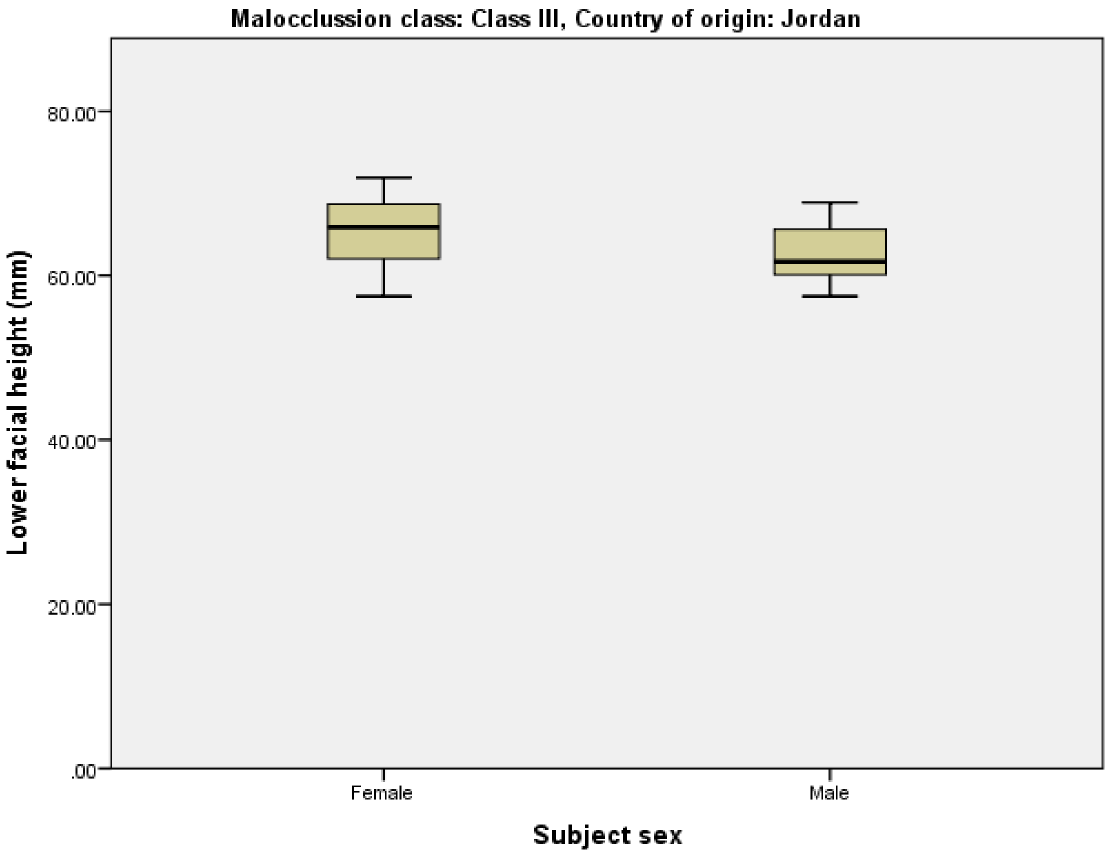

Malocclussion class: Class I, Country of origin: Scotland
Lower facial height (mm)
60.00
40.00
20.00
.00
Female
Male
Subject sex

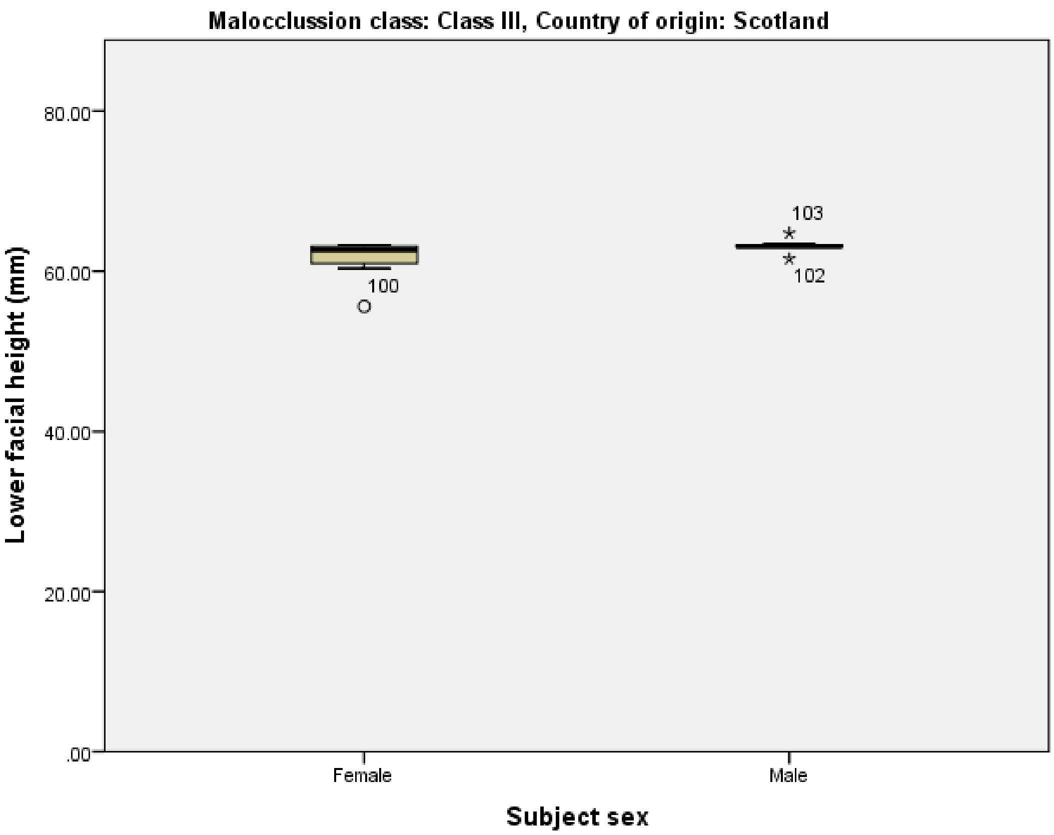

Malocclussion class: Class II div 1, Country of origin: Jordan
Lower facial height (mm)
100.00
80.00
60.00
40.00
20.00
.00
31
Female
Male
Subject sex

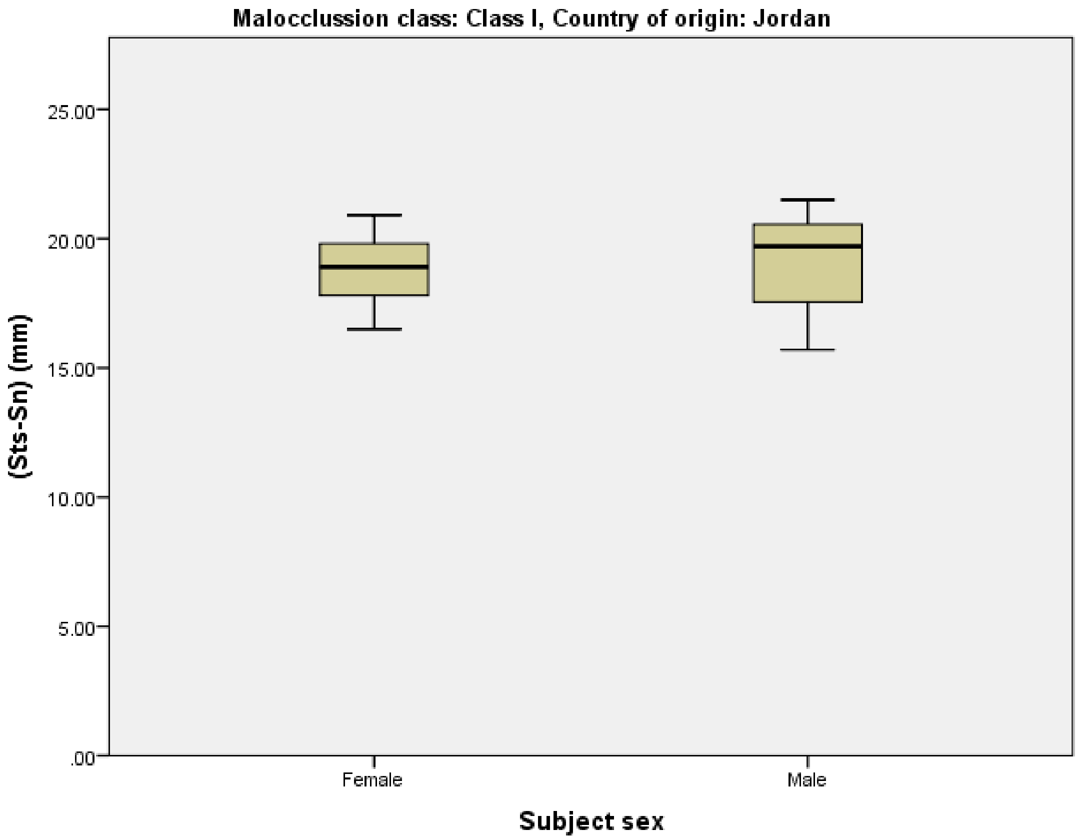

Malocclussion class: Class II div 1, Country of origin: Scotland
Lower facial height (mm)
100.00
80.00
60.00
40.00
20.00
.00
51
45
Female
Male
Subject sex

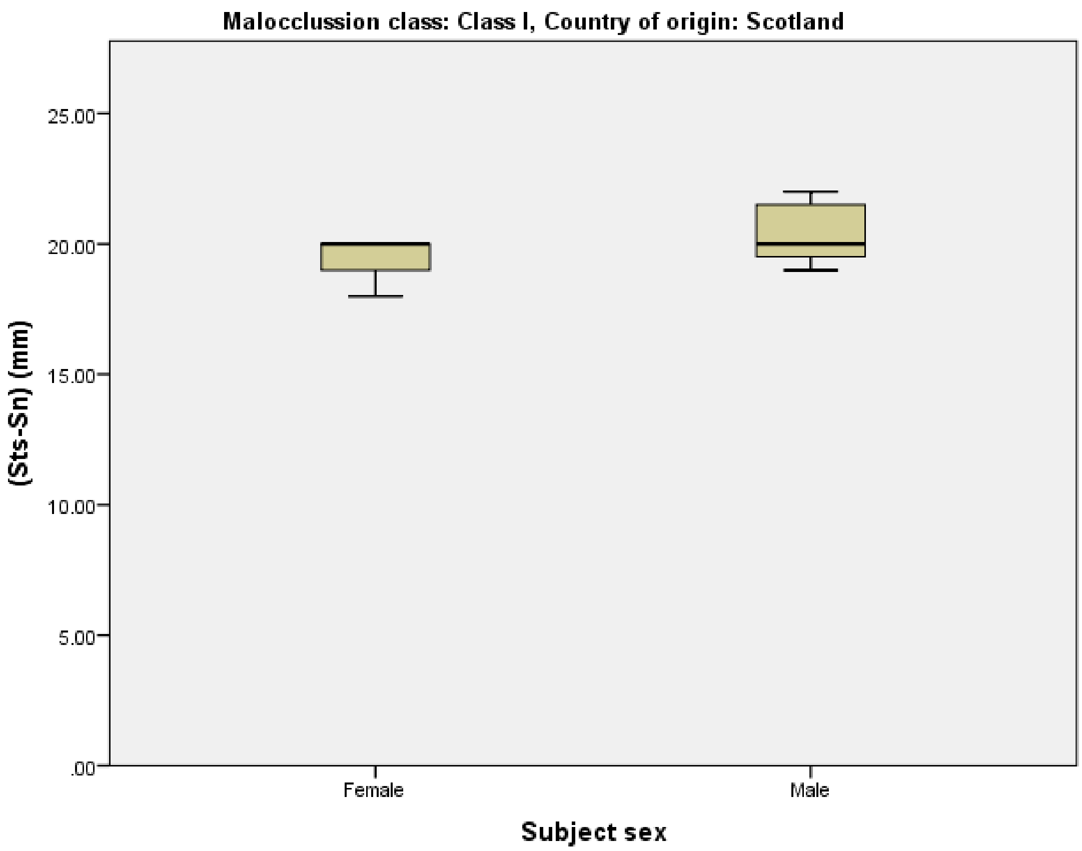

Malocclussion class: Class II div 2, Country of origin: Jordan
Lower facial height (mm)
80.00
60.00
40.00
20.00
.00
70
Female
Male
Subject sex

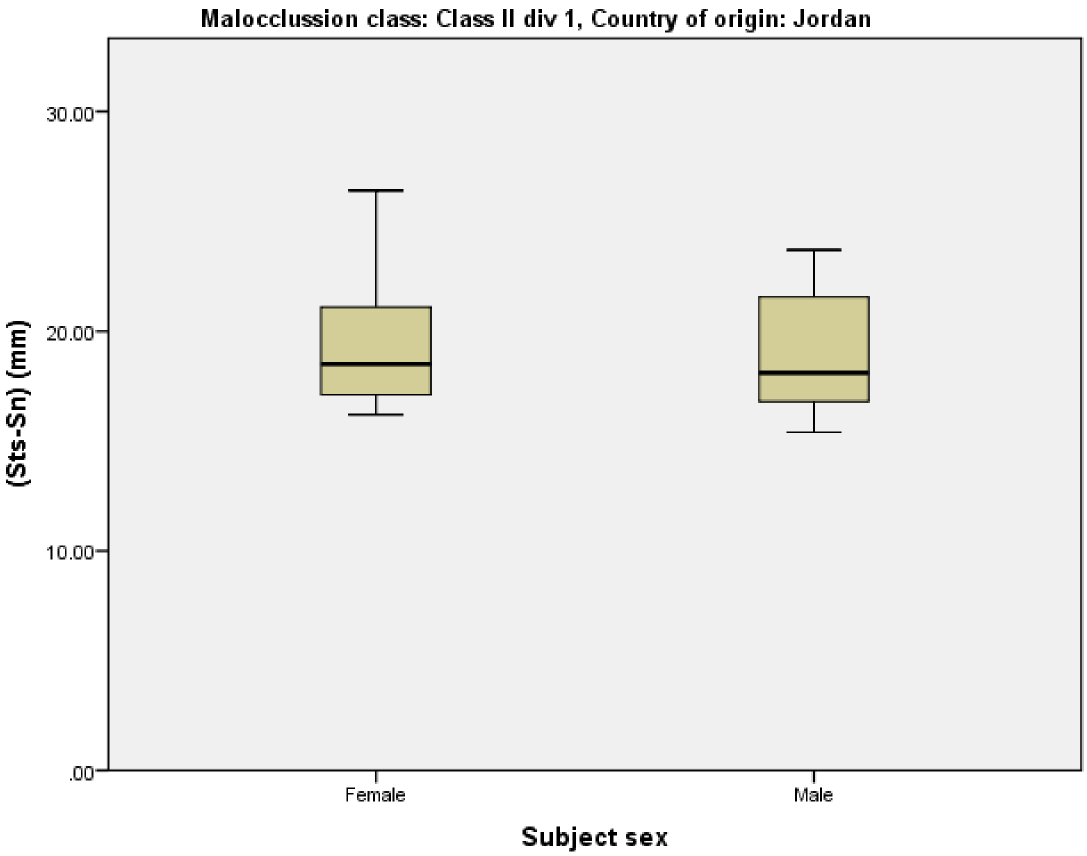

Malocclussion class: Class II div 2, Country of origin: Scotland
Lower facial height (mm)
80.00
60.00
40.00
20.00
.00
Female
Male
Subject sex

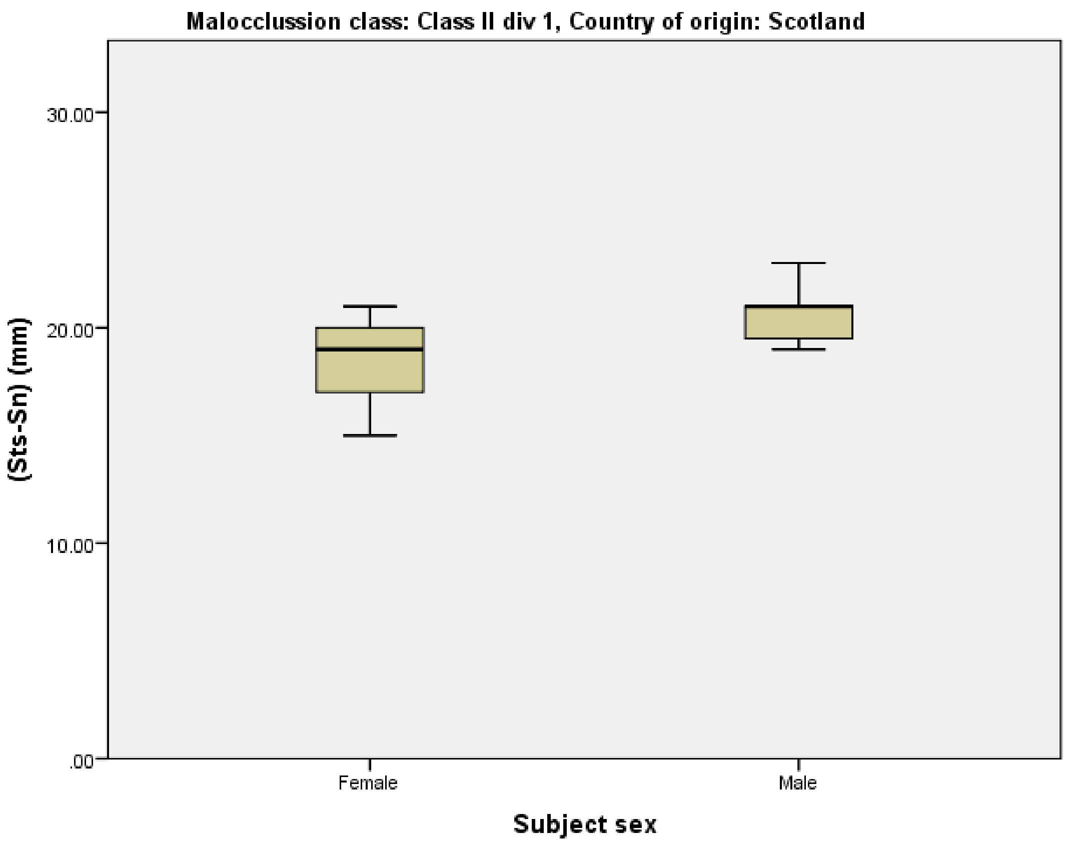

Malocclussion class: Class III, Country of origin: Jordan
80.00
60.00
40.00
20.00
.00
Lower facial height (mm)
Female
Male
Subject sex

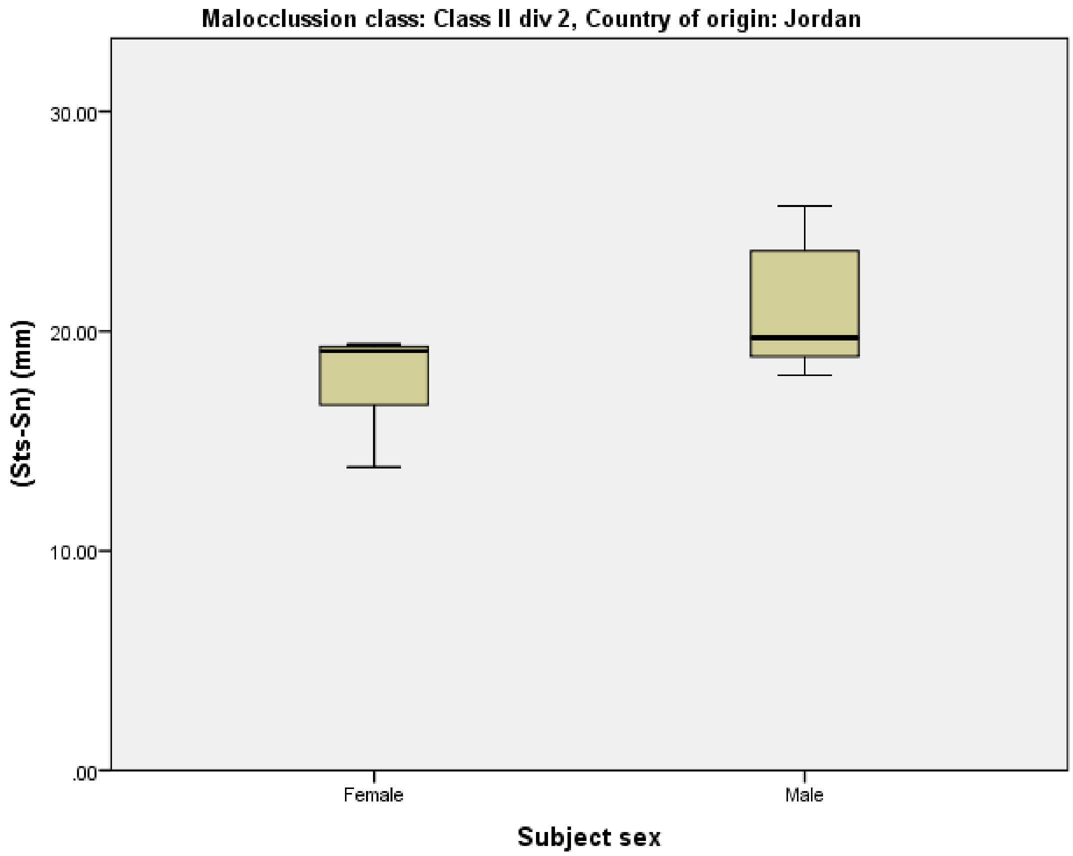

Malocclussion class: Class III, Country of origin: Scotland
80.00
60.00
40.00
20.00
.00
Lower facial height (mm)
100
103
102
Female
Male
Subject sex


Malocclussion class: Class I, Country of origin: Jordan
25.00
20.00
15.00
10.00
5.00
.00
(Sts-Sn) (mm)
Female
Male
Subject sex

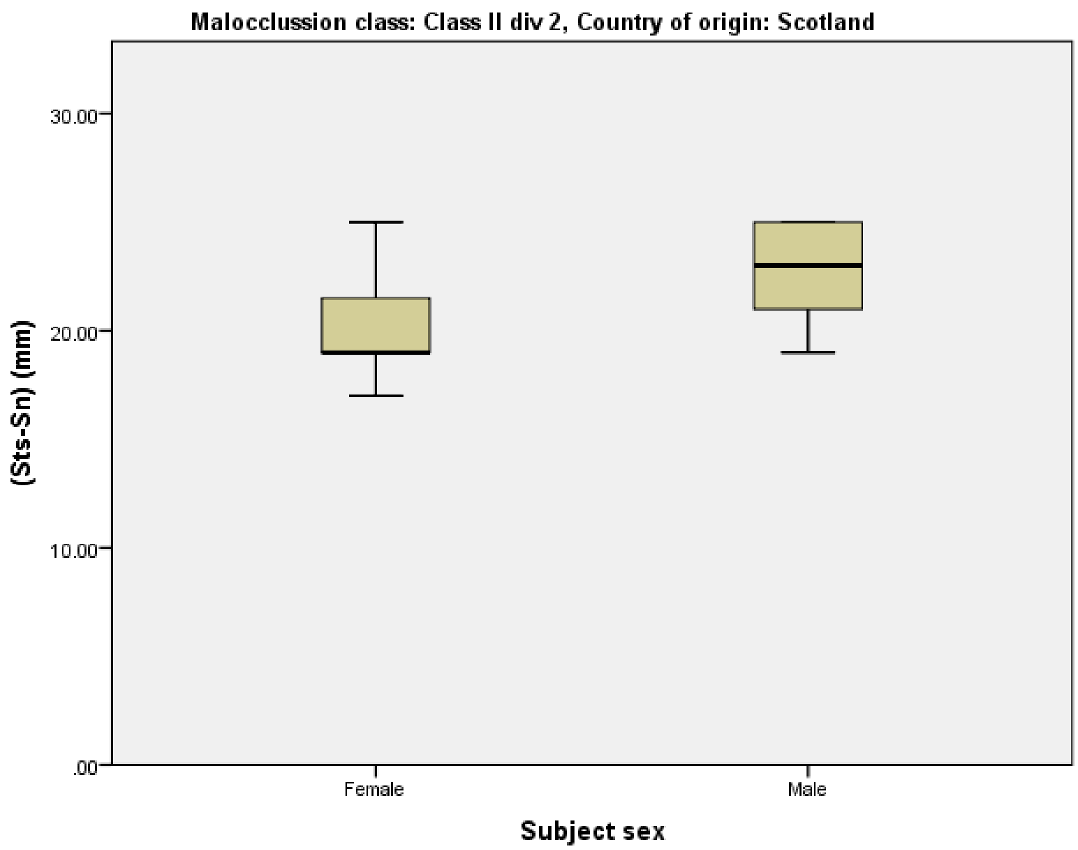

Malocclussion class: Class I, Country of origin: Scotland
25.00
20.00
15.00
10.00
5.00
.00
(Sts-Sn) (mm)
Female
Male
Subject sex


Malocclussion class: Class II div 1, Country of origin: Jordan
30.00
20.00
10.00
.00
(Sts-Sn) (mm)
Female
Male
Subject sex

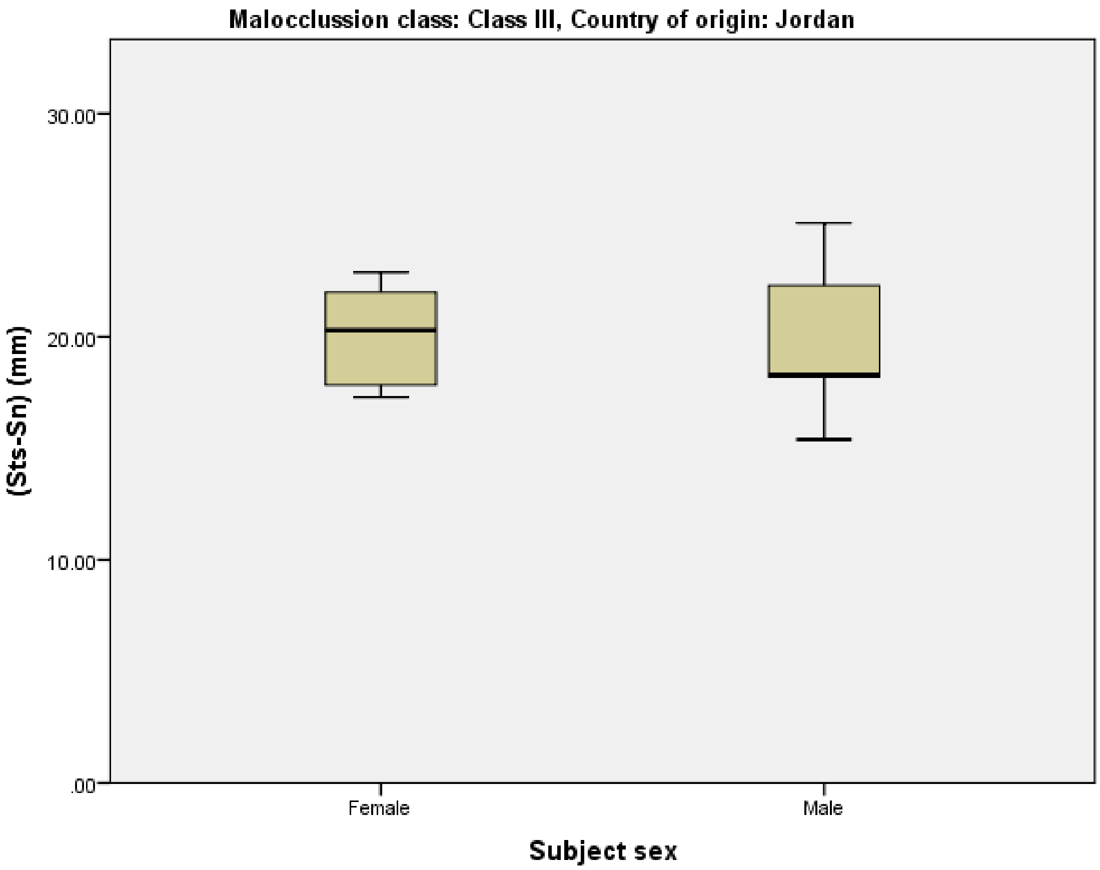

Malocclussion class: Class II div 1, Country of origin: Scotland
30.00
20.00
10.00
.00
(Sts-Sn) (mm)
Female
Male
Subject sex

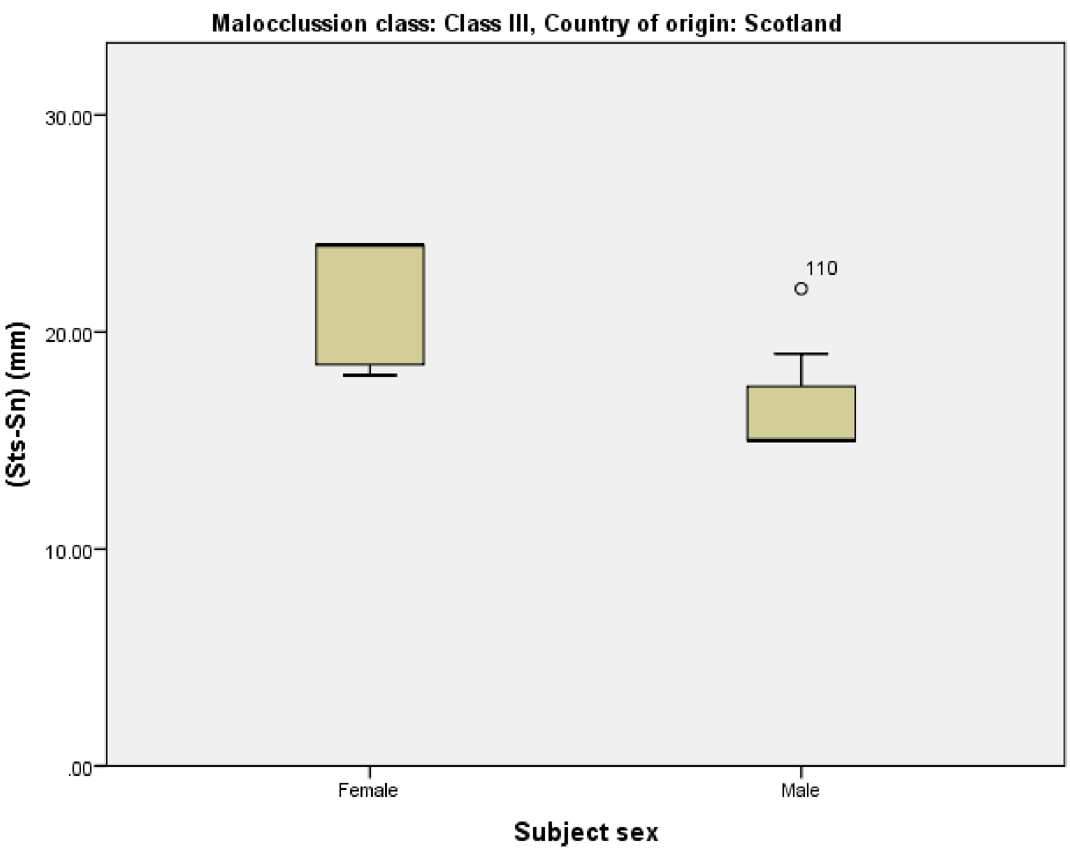


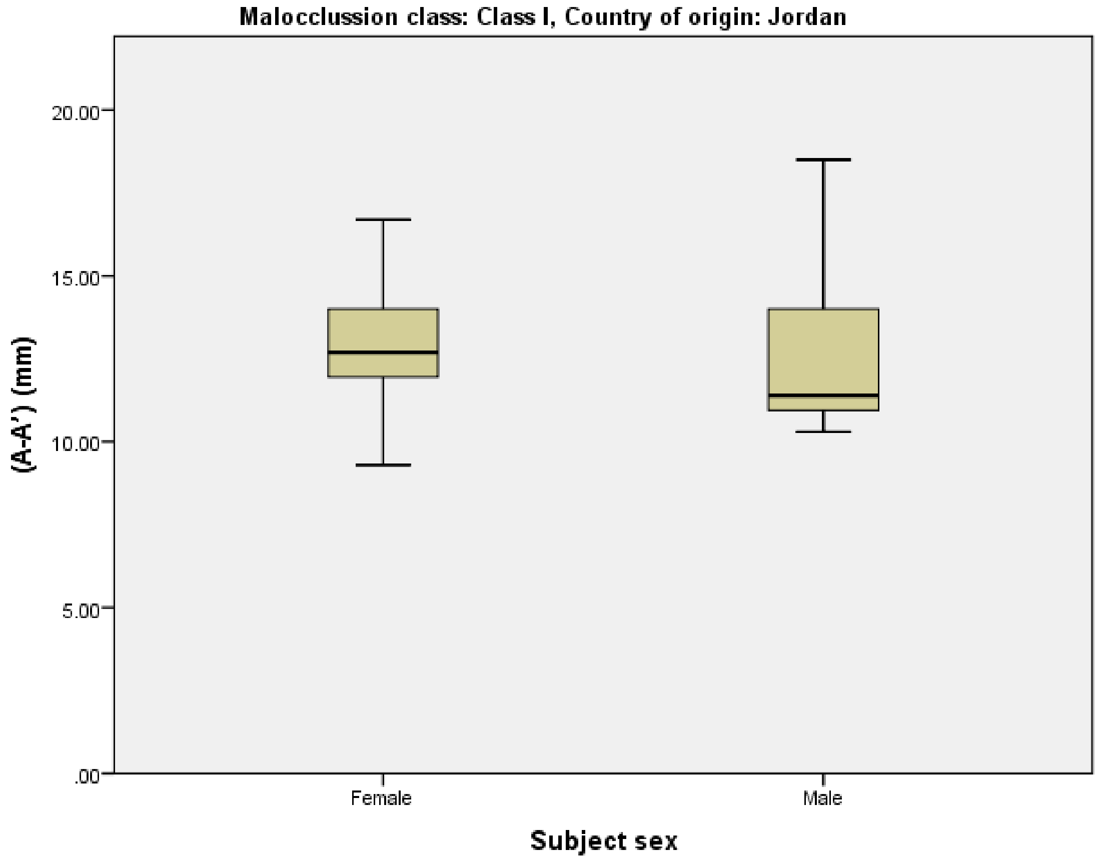
Malocclussion class: Class II div 2, Country of origin: Jordan
30.00
20.00
10.00
.00
(Sts-Sn) (mm)
Female
Male
Subject sex

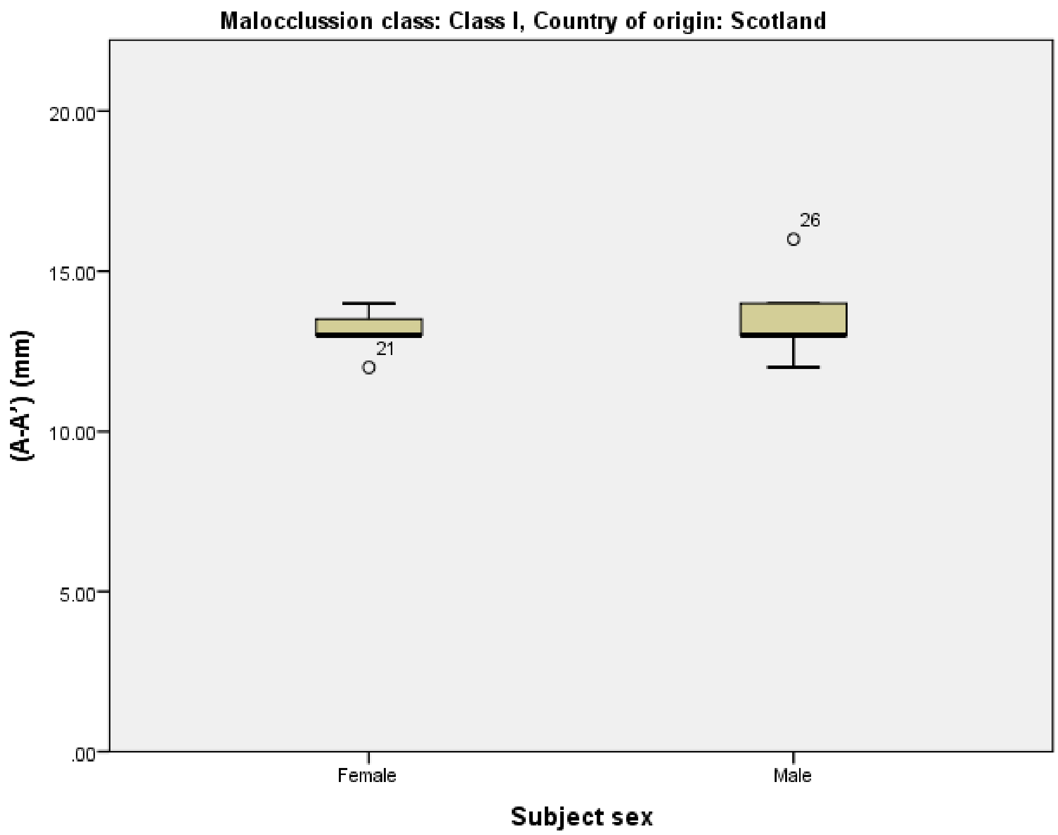


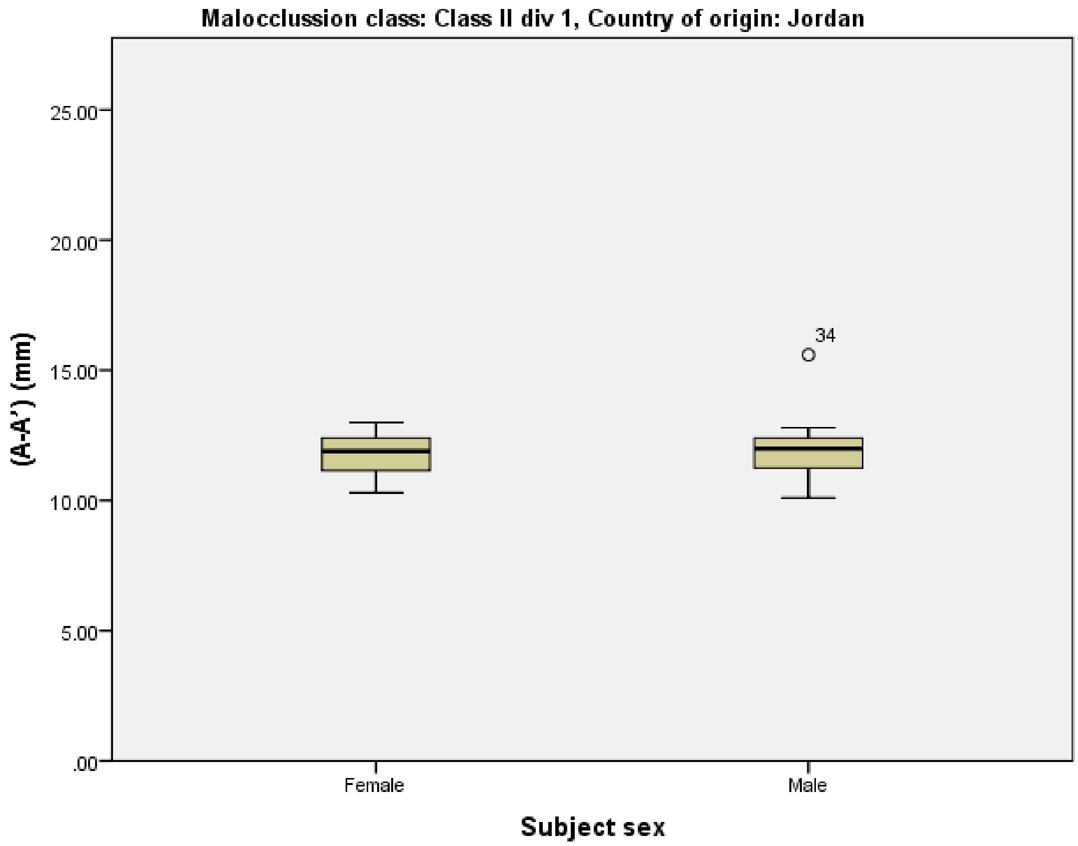
Malocclussion class: Class II div 2, Country of origin: Scotland
30.00
20.00
10.00
.00
(Sts-Sn) (mm)
Female
Male
Subject sex


Malocclussion class: Class III, Country of origin: Jordan
30.00
20.00
10.00
.00
(Sts-Sn) (mm)
Female
Male
Subject sex

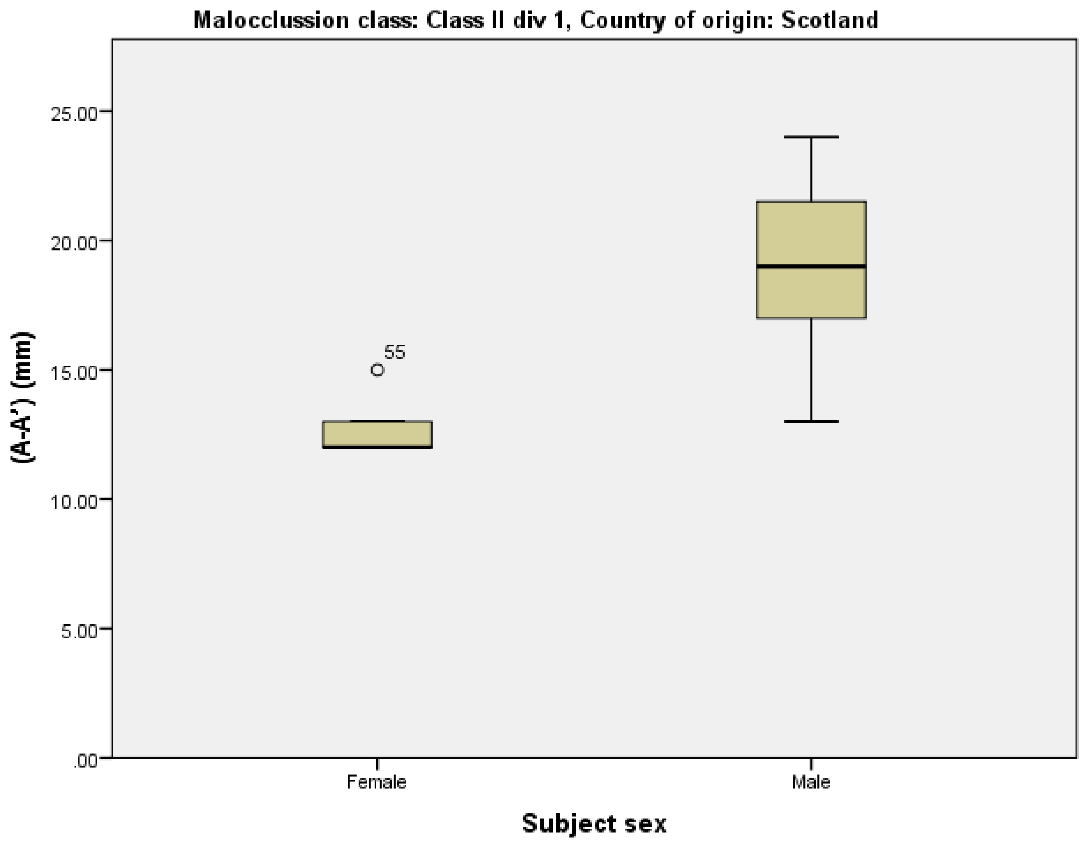

Malocclussion class: Class III, Country of origin: Scotland
30.00
20.00
10.00
.00
(Sts-Sn) (mm)
110
Female
Male
Subject sex


Malocclussion class: Class I, Country of origin: Jordan
20.00
15.00
10.00
5.00
.00
(A-A') (mm)
Female
Male
Subject sex

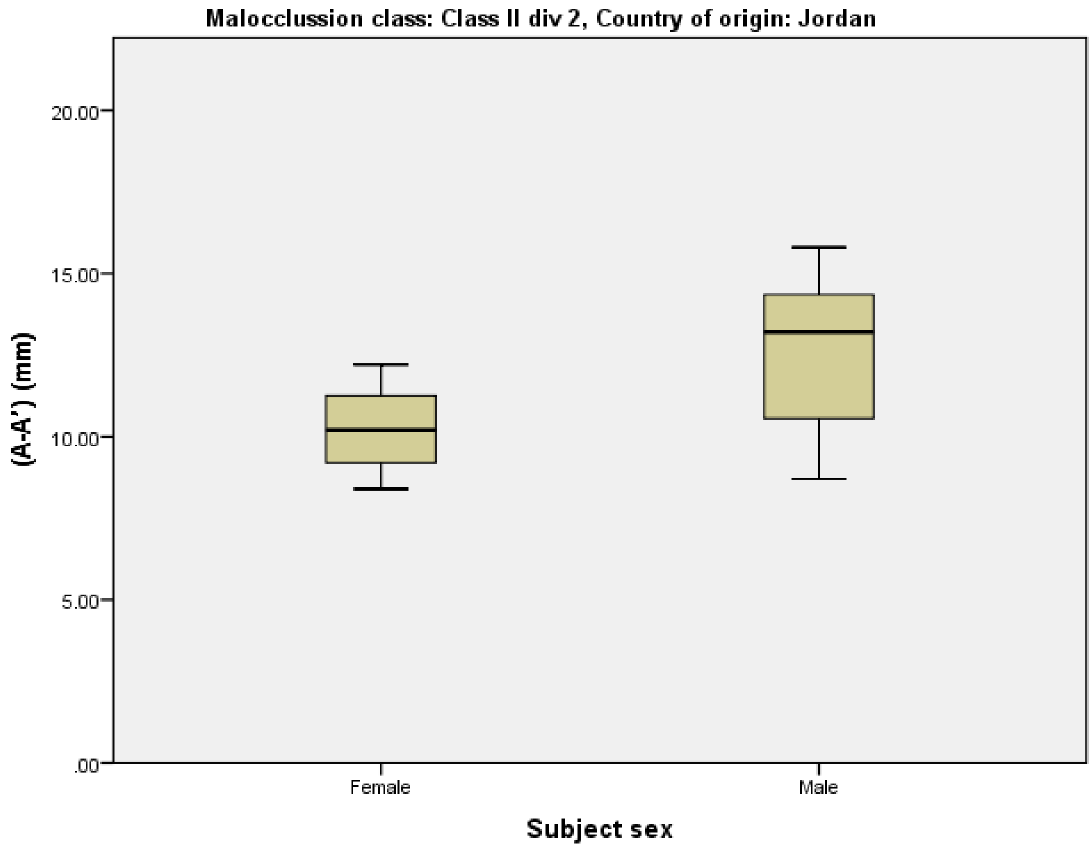

Malocclussion class: Class I, Country of origin: Scotland
20.00
15.00
10.00
5.00
.00
(A-A') (mm)
26
21
Female
Male
Subject sex

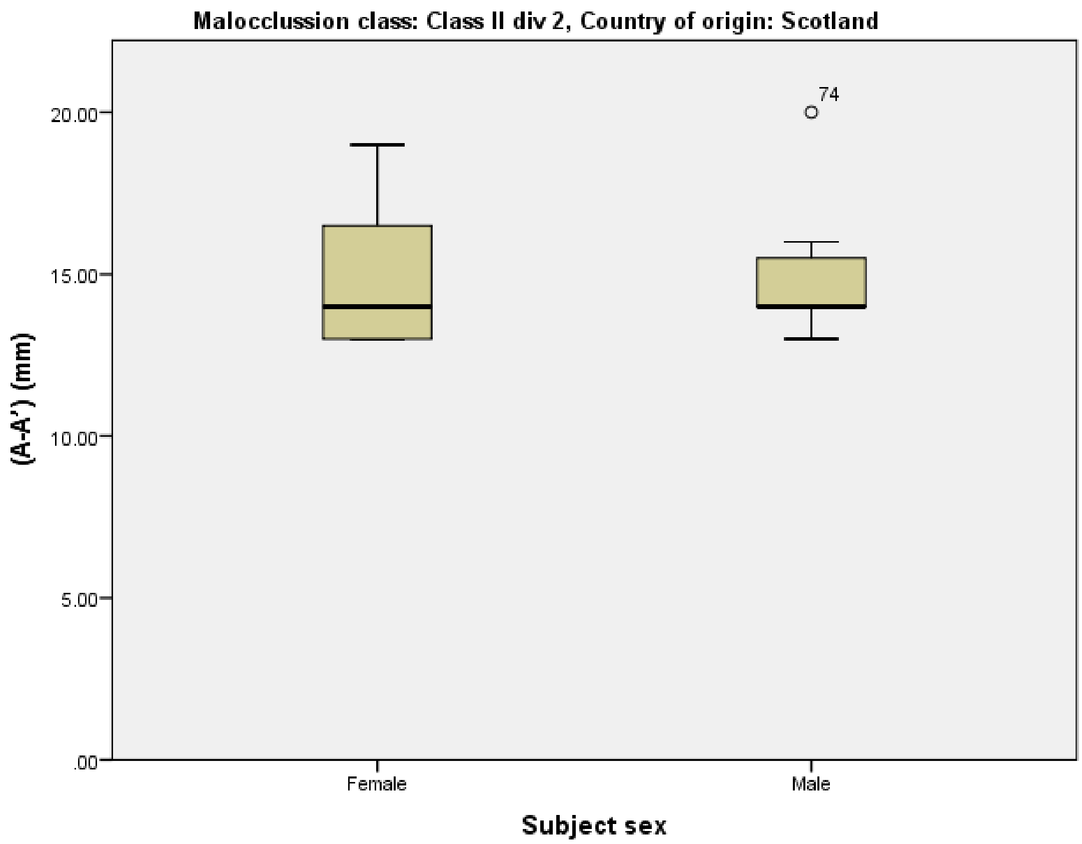


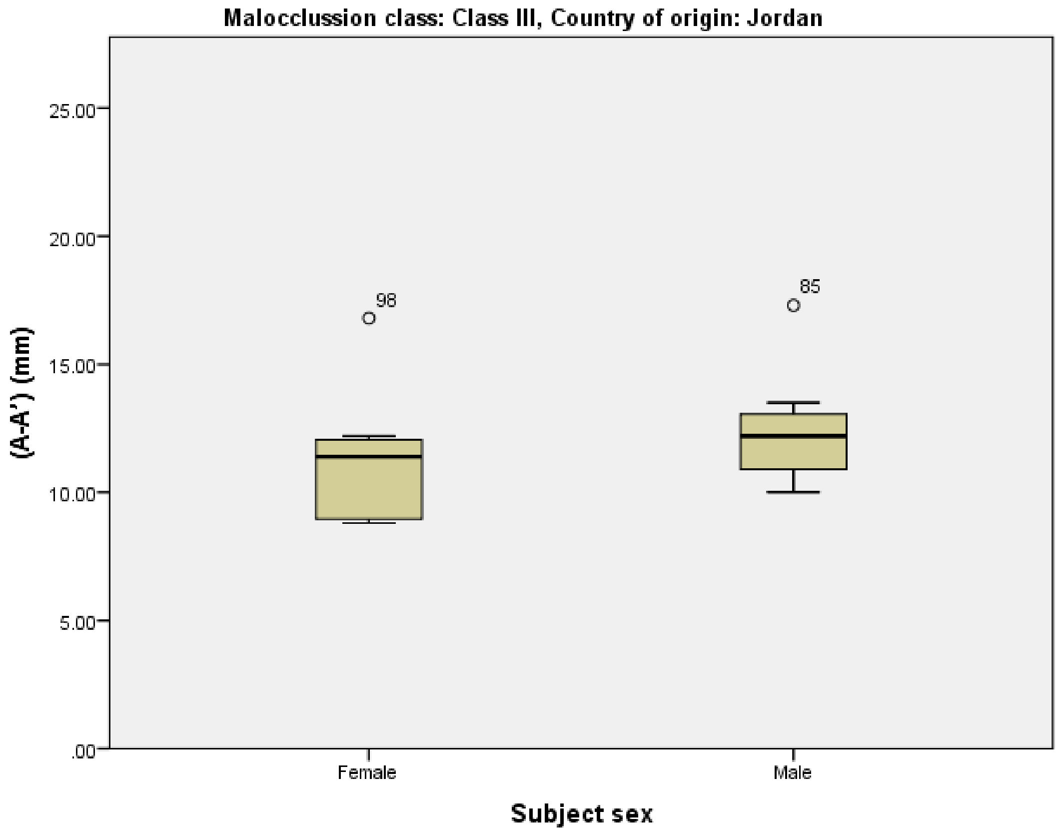
Malocclussion class: Class II div 1, Country of origin: Jordan
25.00
20.00
15.00
10.00
5.00
.00
(A-A') (mm)
34
Female
Male
Subject sex

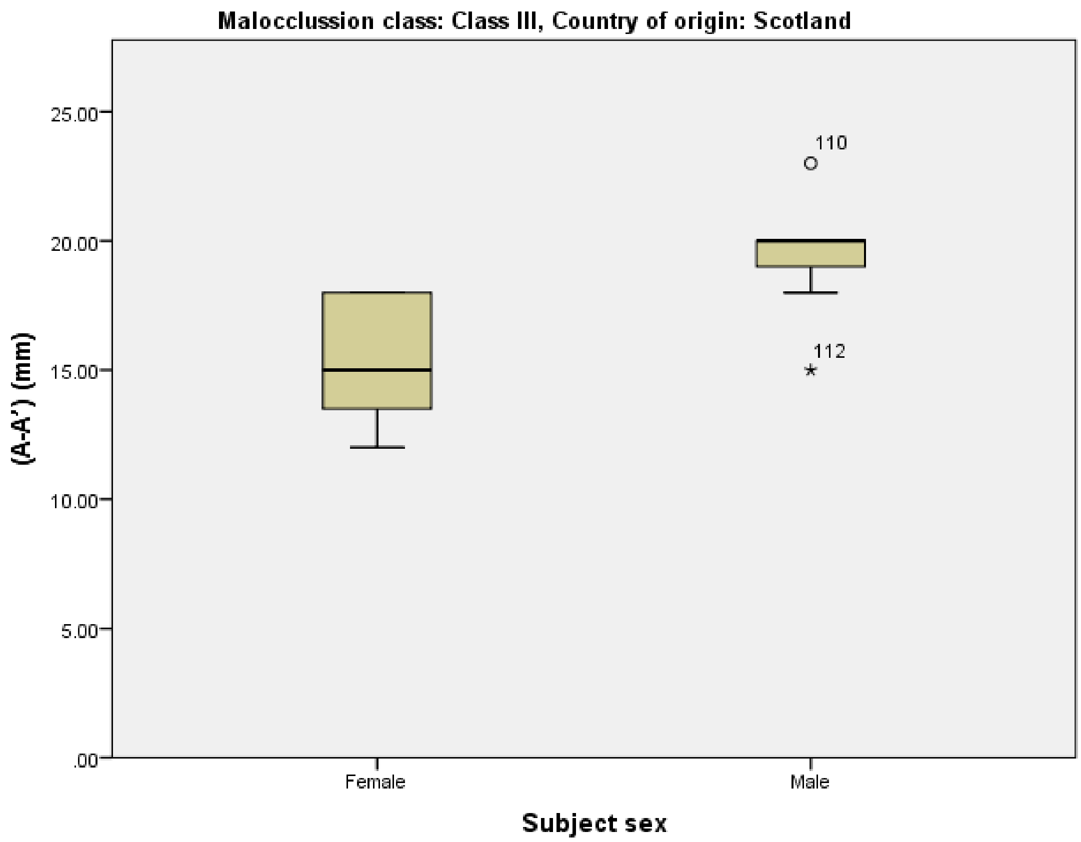


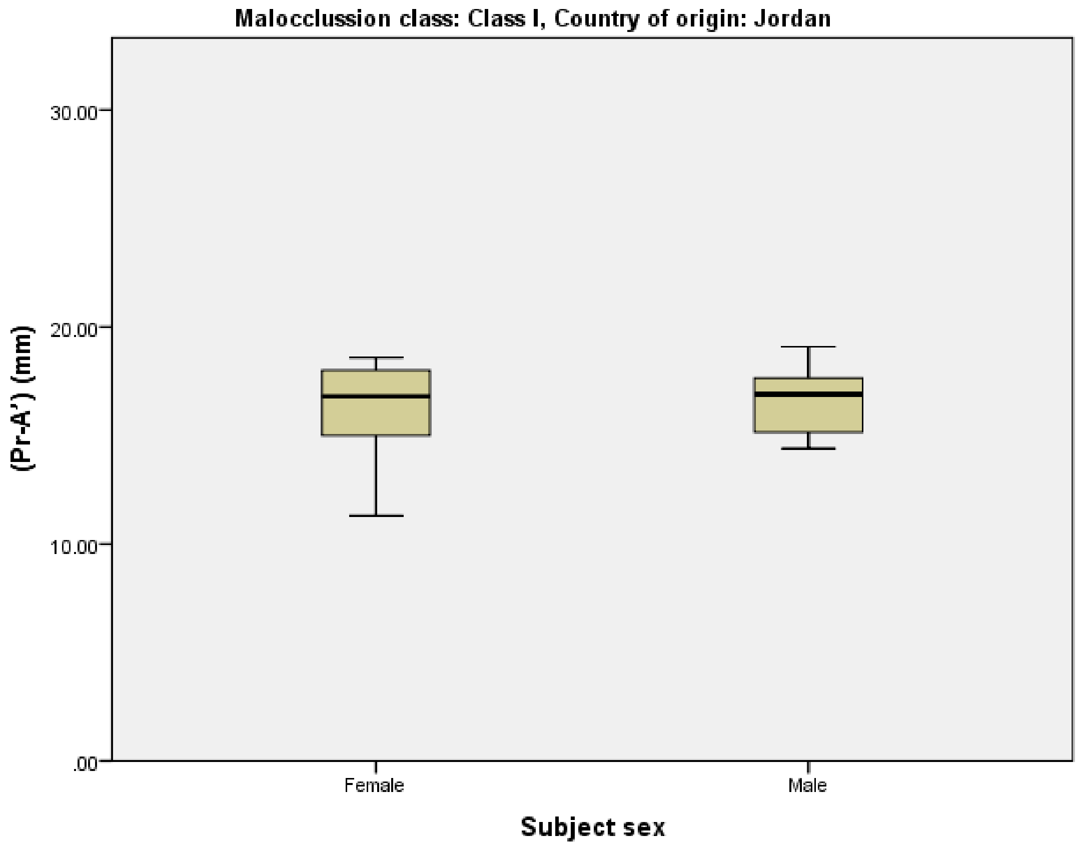
Malocclussion class: Class II div 1, Country of origin: Scotland
25.00
20.00
15.00
10.00
5.00
.00
(A-A') (mm)
55
Female
Male
Subject sex

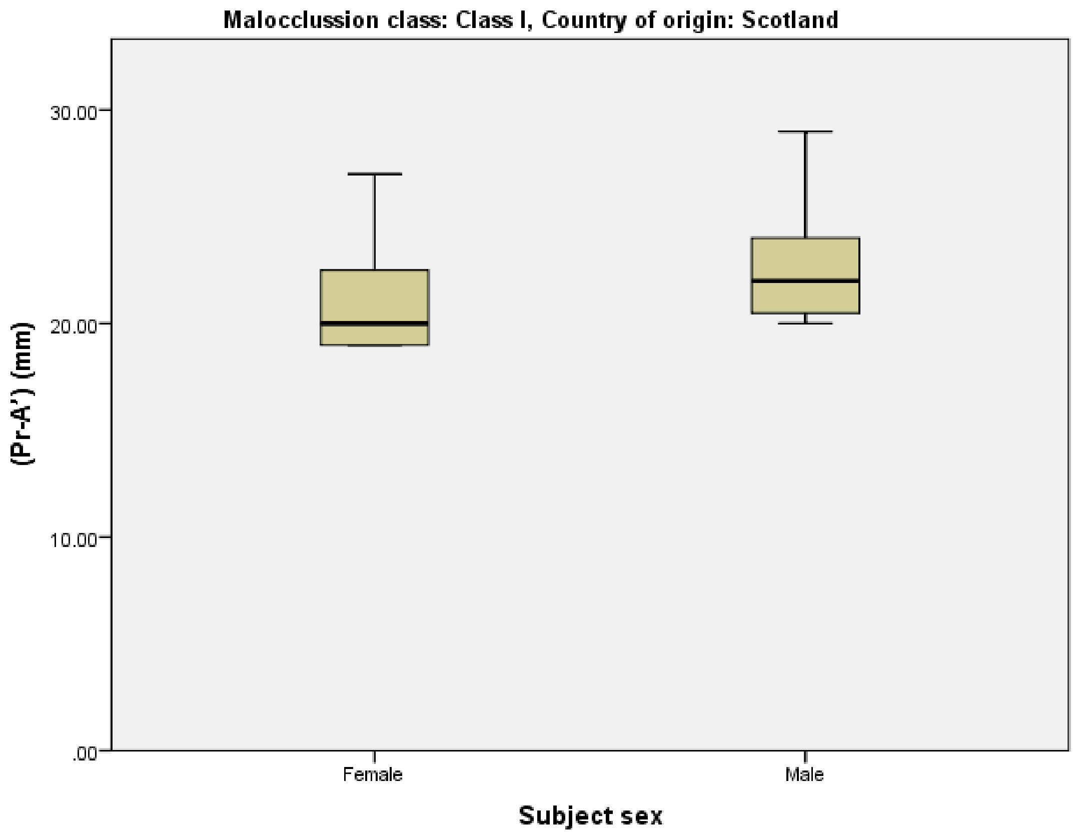

Malocclussion class: Class II div 2, Country of origin: Jordan
(A-A') (mm)
20.00
15.00
10.00
5.00
.00
Female
Male
Subject sex

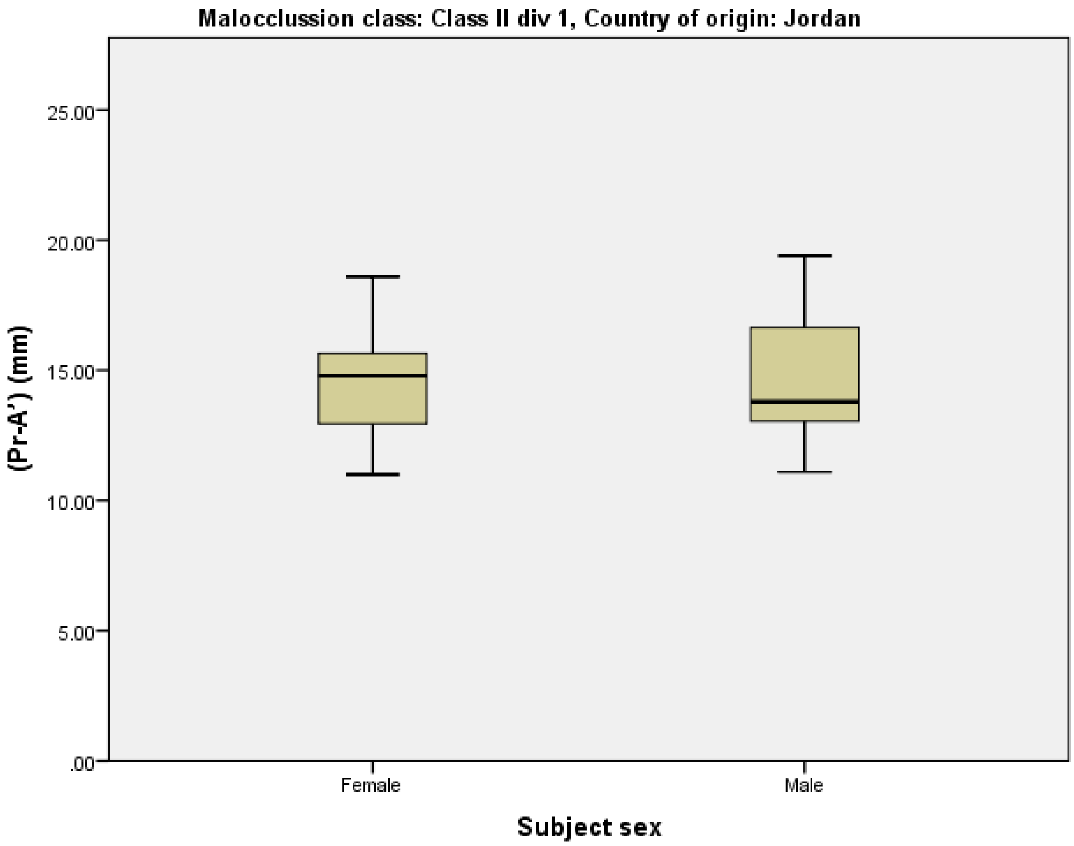

Malocclussion class: Class II div 2, Country of origin: Scotland
(A-A') (mm)
20.00
15.00
10.00
5.00
.00
74
Female
Male
Subject sex

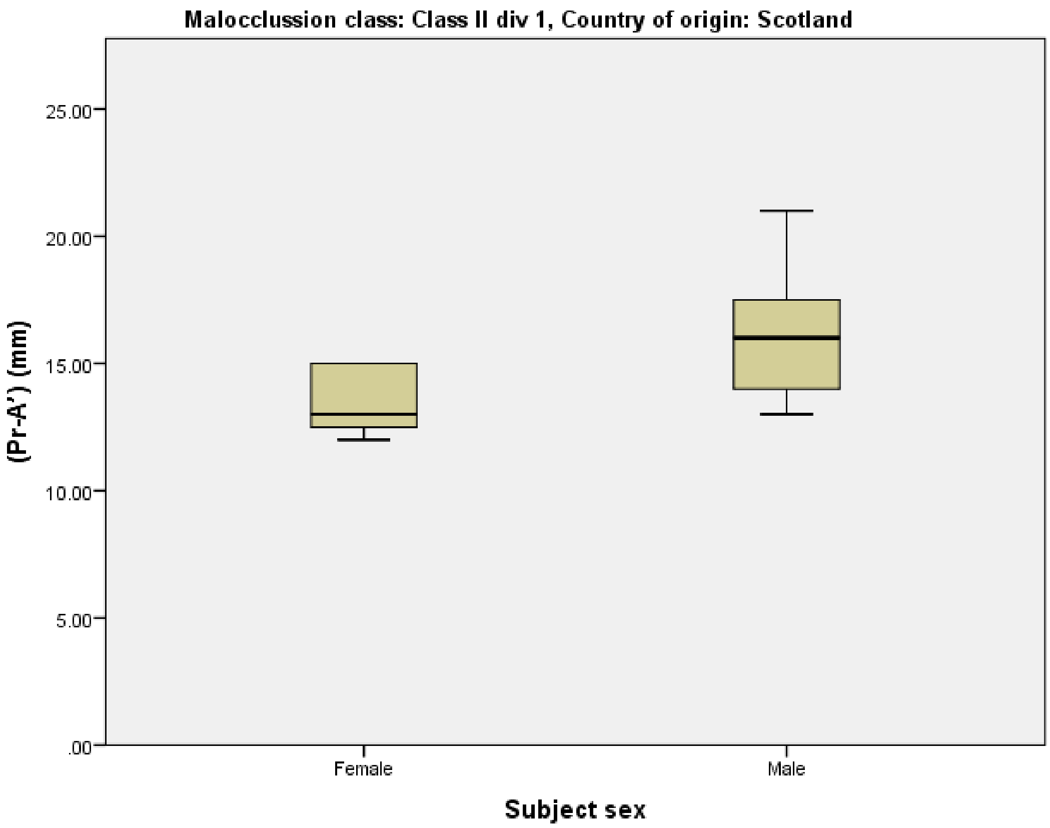

Malocclussion class: Class III, Country of origin: Jordan
25.00
20.00
15.00
10.00
5.00
.00
(A-A') (mm)
98
85
Female
Male
Subject sex

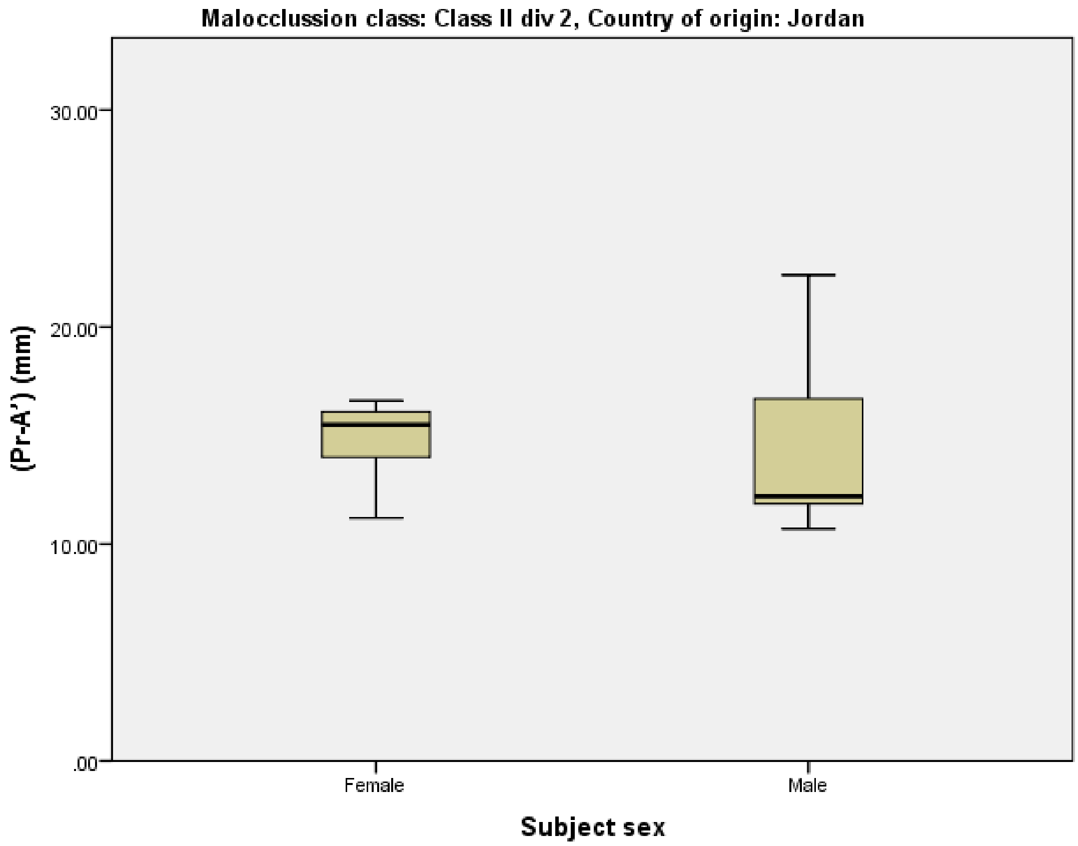

Malocclussion class: Class III, Country of origin: Scotland
25.00
20.00
15.00
10.00
5.00
.00
(A-A') (mm)
110
112
Female
Male
Subject sex

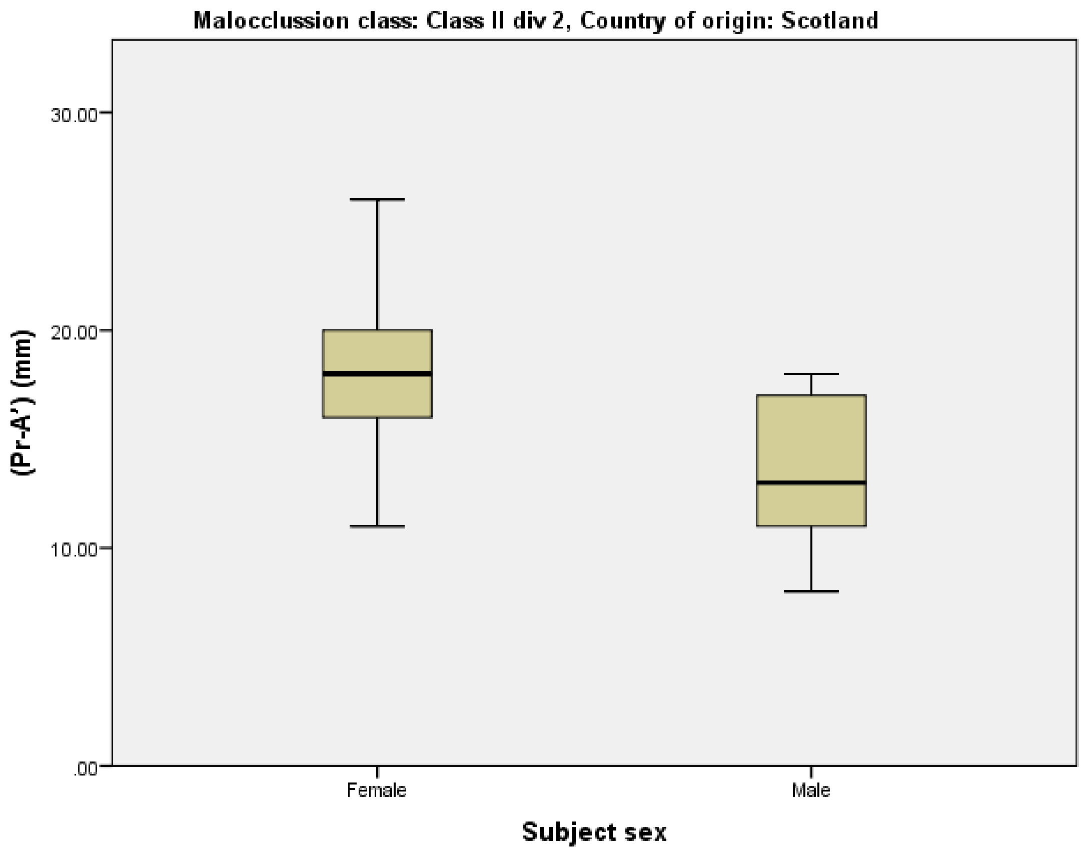

Malocclussion class: Class I, Country of origin: Jordan
30.00
20.00
10.00
.00
(Pr-A') (mm)
Female
Male
Subject sex

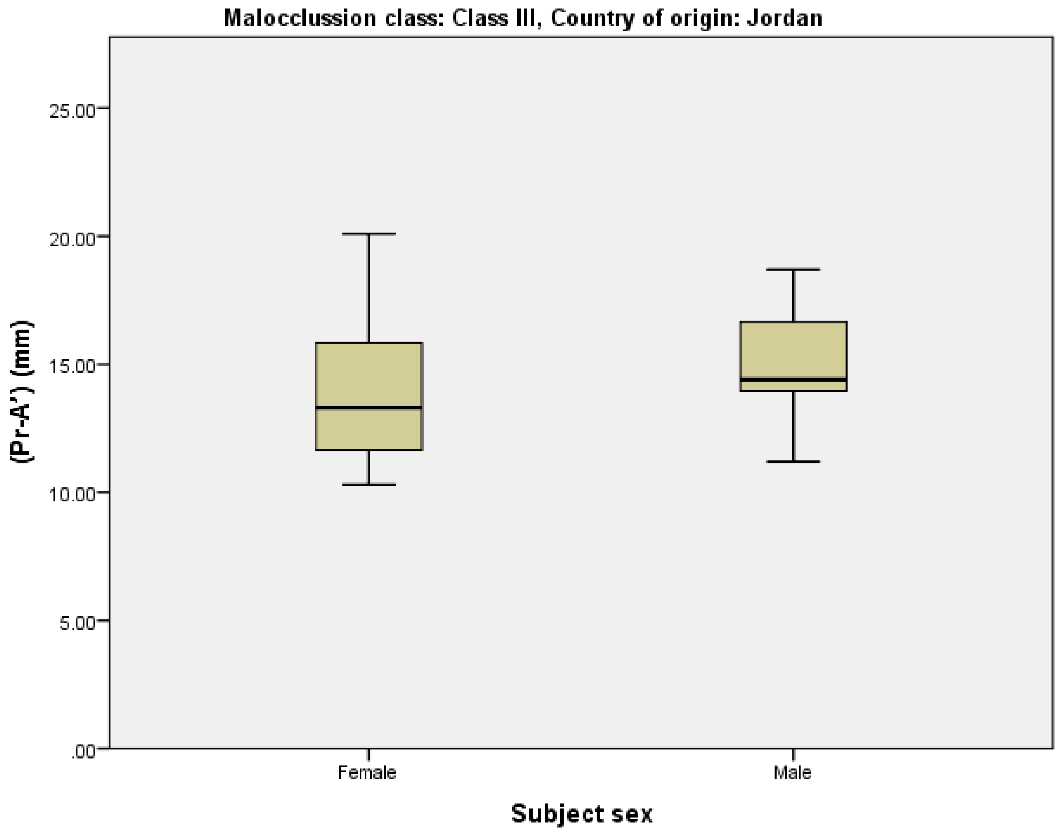

Malocclussion class: Class I, Country of origin: Scotland
30.00
20.00
10.00
.00
(Pr-A') (mm)
Female
Male
Subject sex

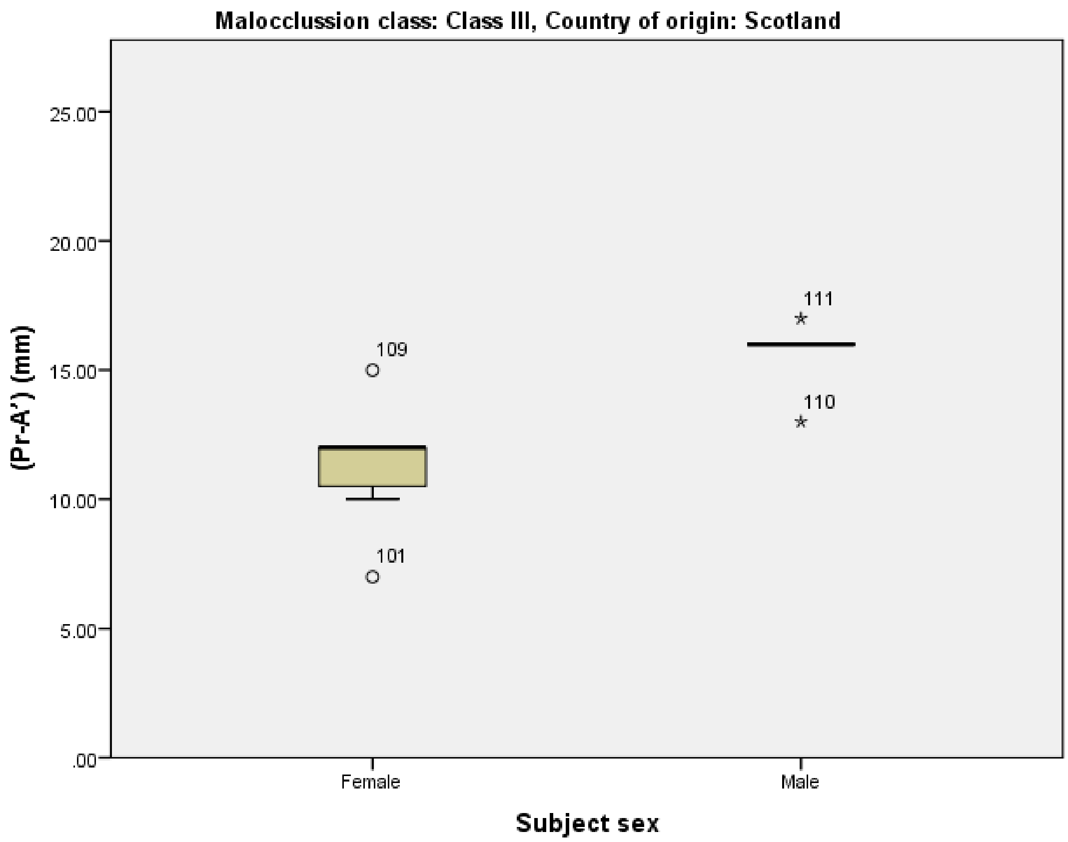

Malocclussion class: Class II div 1, Country of origin: Jordan
25.00
20.00
15.00
10.00
5.00
.00
(Pr-A') (mm)
Female
Male
Subject sex

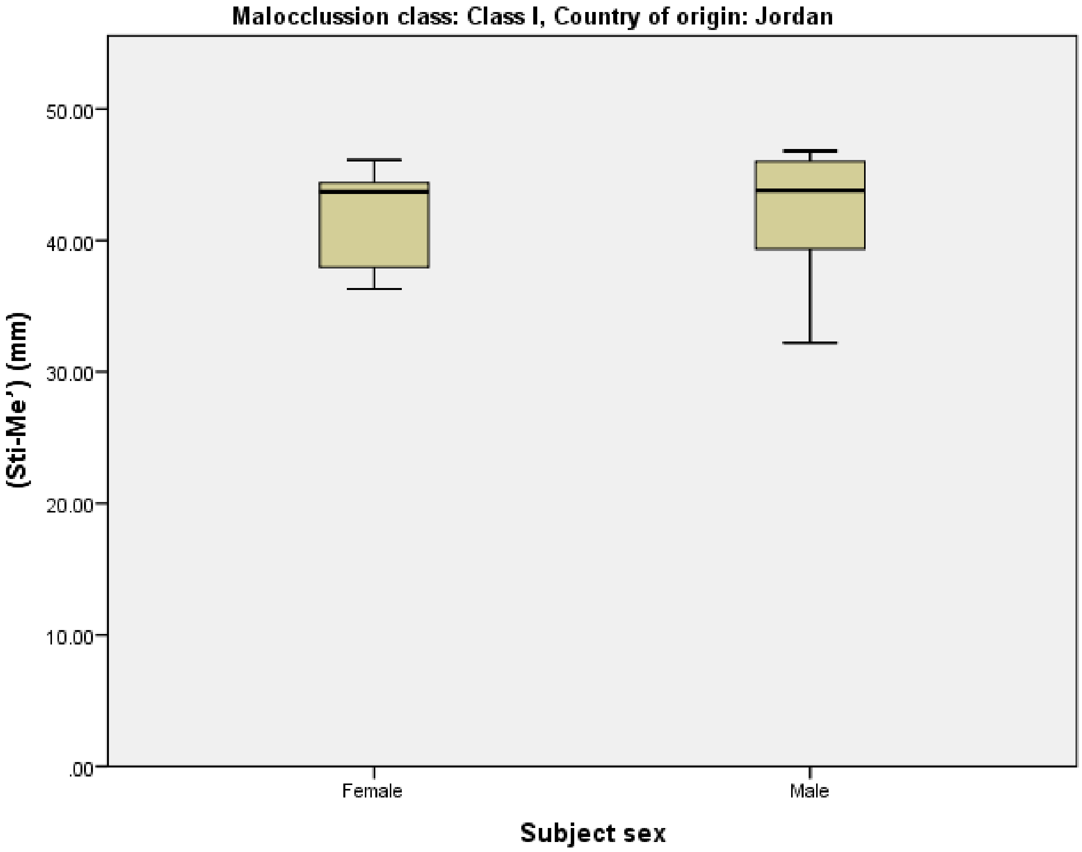

Malocclussion class: Class II div 1, Country of origin: Scotland
25.00
20.00
15.00
10.00
5.00
.00
(Pr-A') (mm)
Female
Male
Subject sex

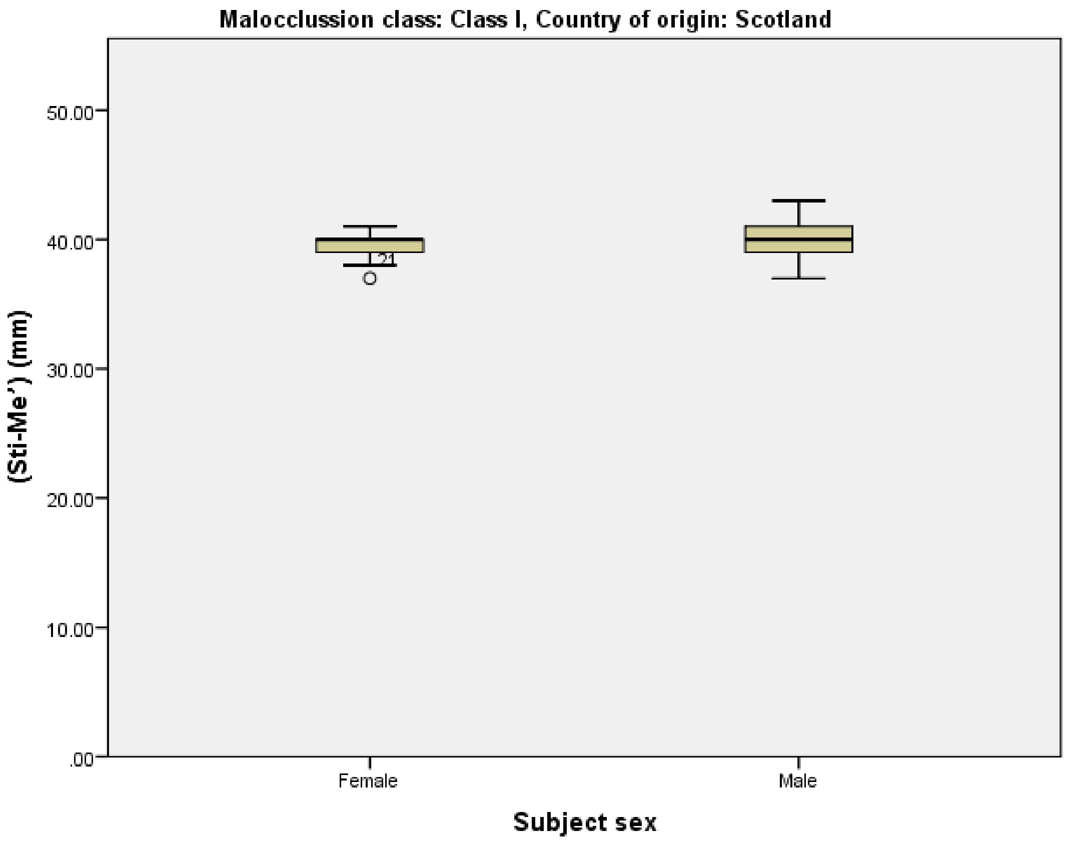

Malocclussion class: Class II div 2, Country of origin: Jordan
30.00
20.00
10.00
.00
(Pr-A') (mm)
Female
Male
Subject sex

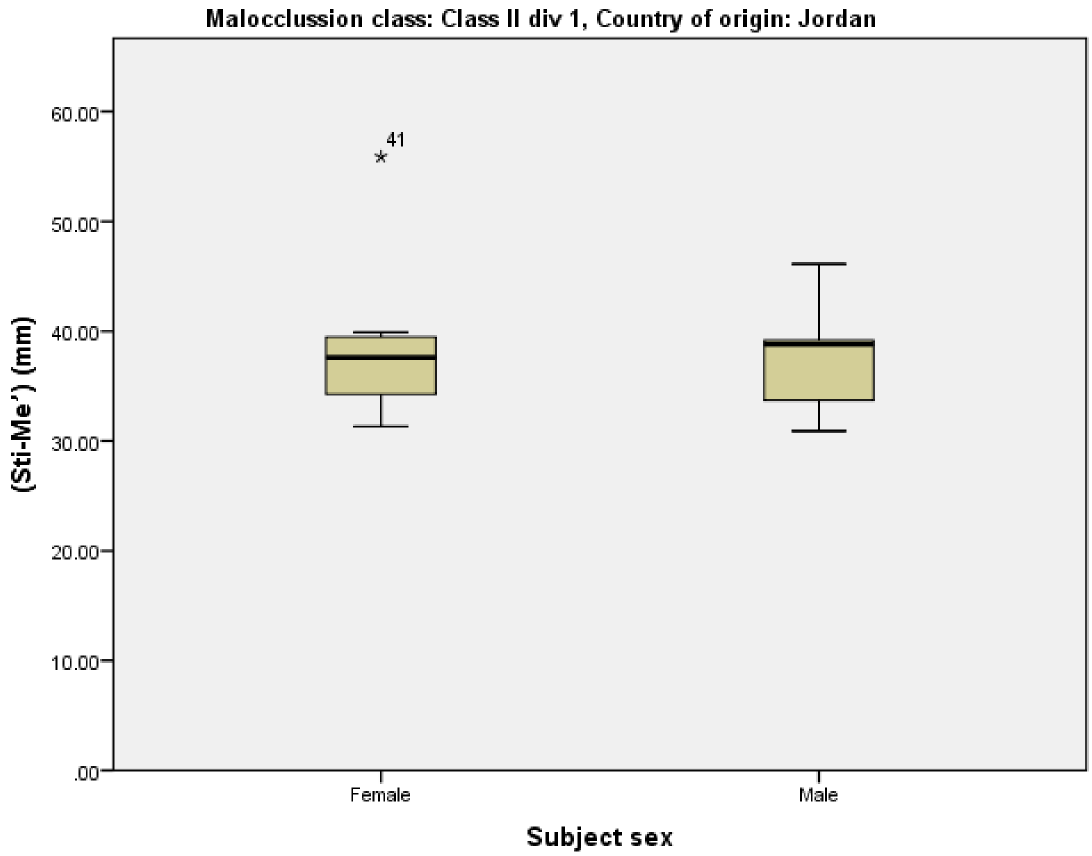

Malocclussion class: Class II div 2, Country of origin: Scotland
30.00
20.00
10.00
.00
(Pr-A') (mm)
Female
Male
Subject sex

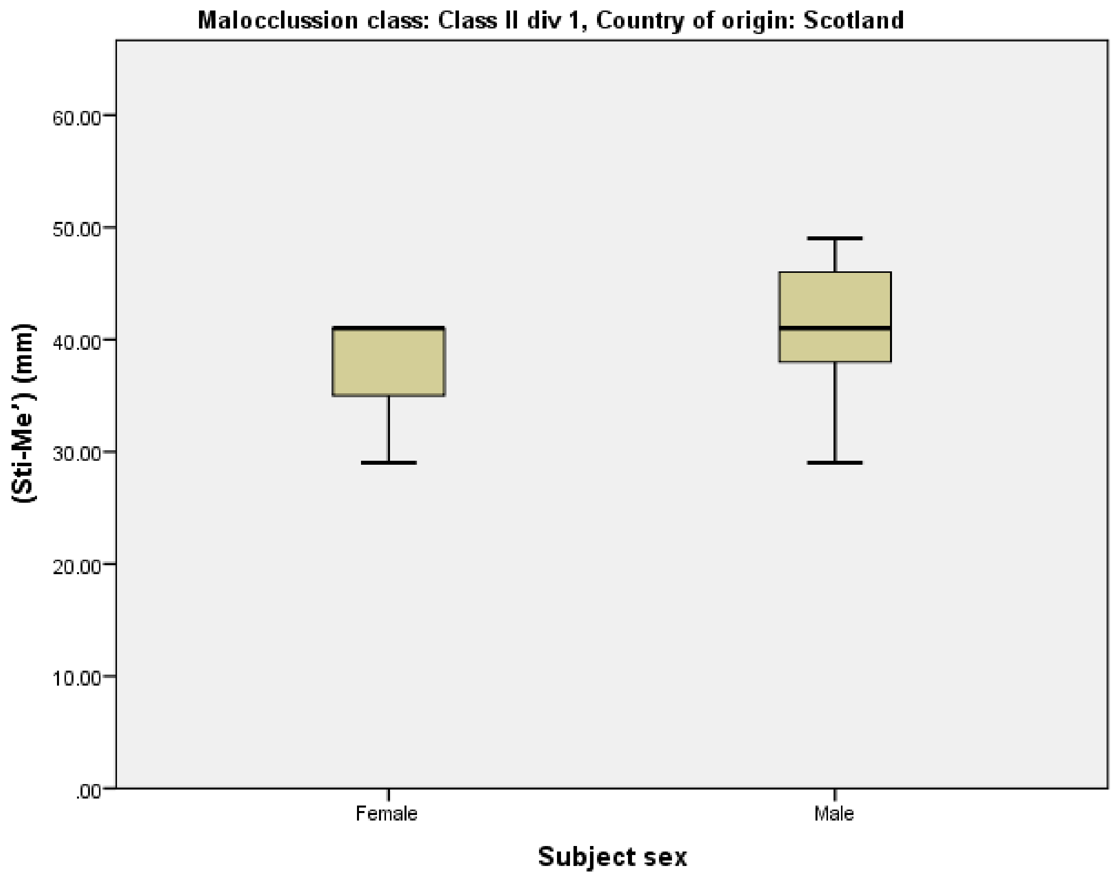

Malocclussion class: Class III, Country of origin: Jordan
25.00
20.00
15.00
10.00
5.00
.00
(Pr-A') (mm)
Female
Male
Subject sex

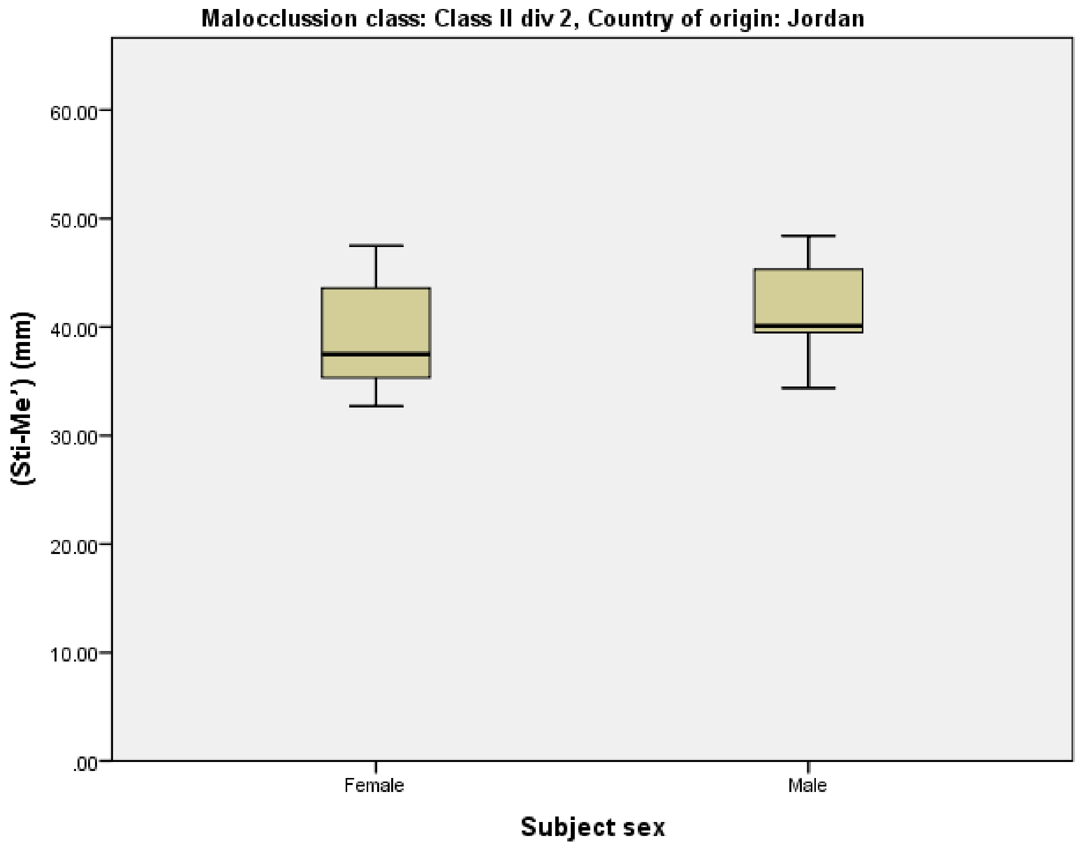

Malocclussion class: Class III, Country of origin: Scotland
25.00
20.00
15.00
10.00
5.00
.00
(Pr-A') (mm)
109
101
111
110
Female
Male
Subject sex

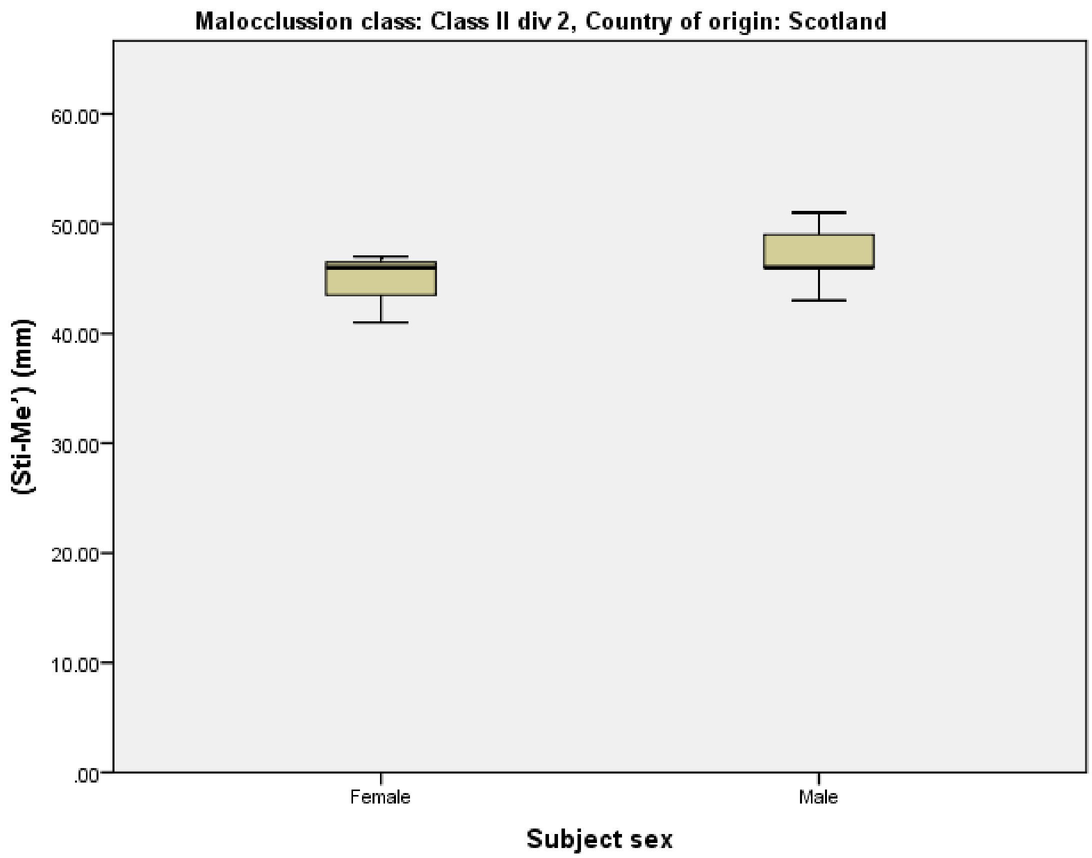

Malocclussion class: Class I, Country of origin: Jordan
50.00
40.00
30.00
20.00
10.00
.00
(Sti-Me') (mm)
Female
Male
Subject sex

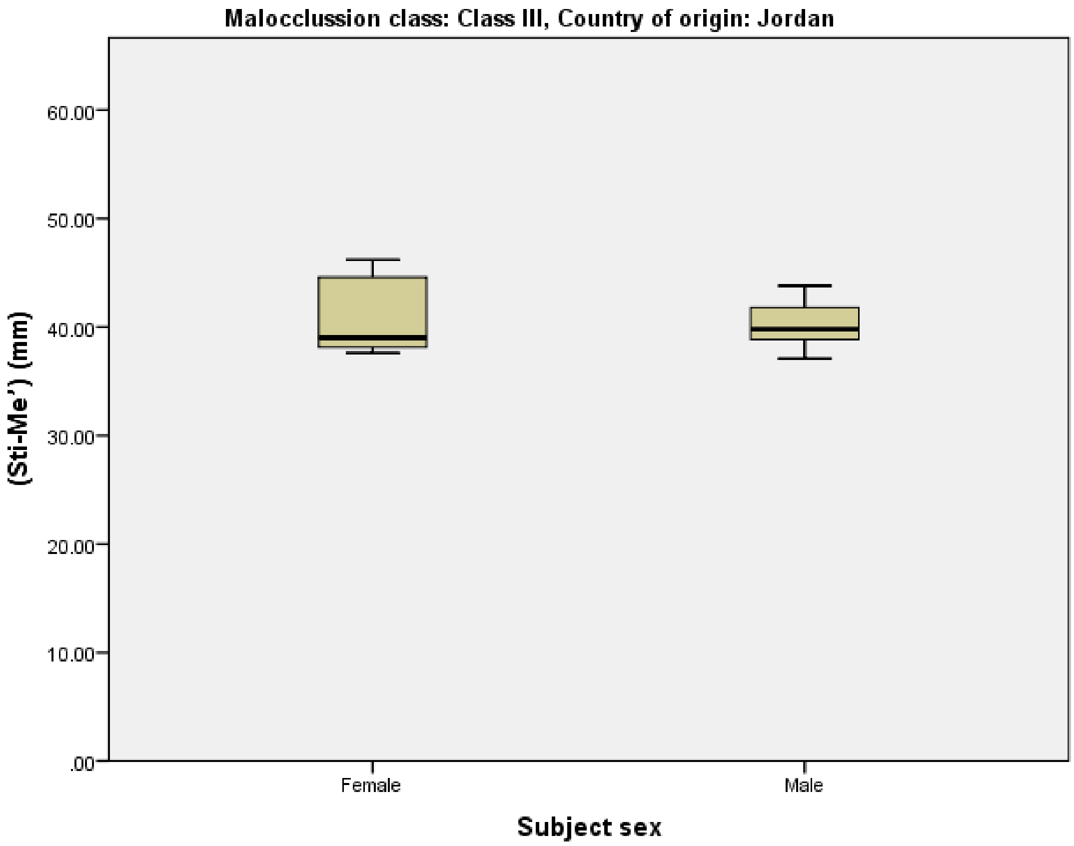

Malocclussion class: Class I, Country of origin: Scotland
50.00
40.00
30.00
20.00
10.00
.00
(Sti-Me') (mm)
21
Female
Male
Subject sex

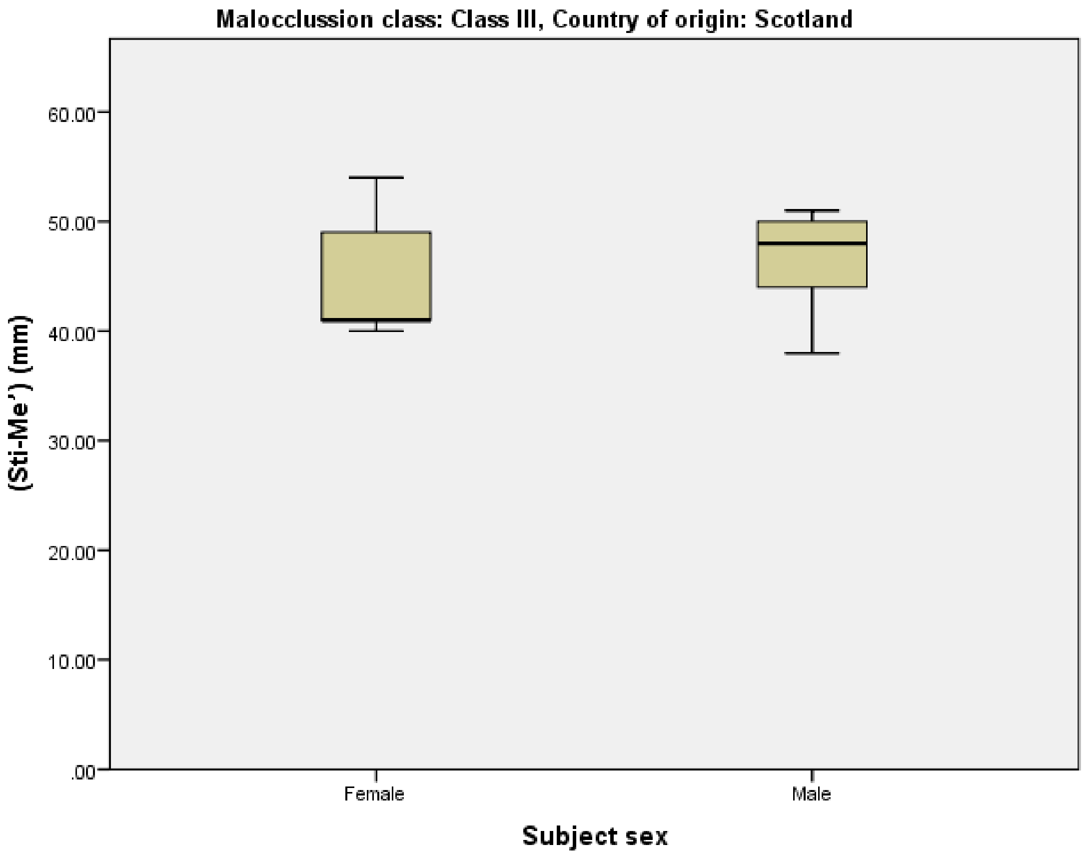

Malocclussion class: Class II div 1, Country of origin: Jordan
60.00
50.00
40.00
30.00
20.00
10.00
.00
41
(Sti-Me') (mm)
Female
Male
Subject sex

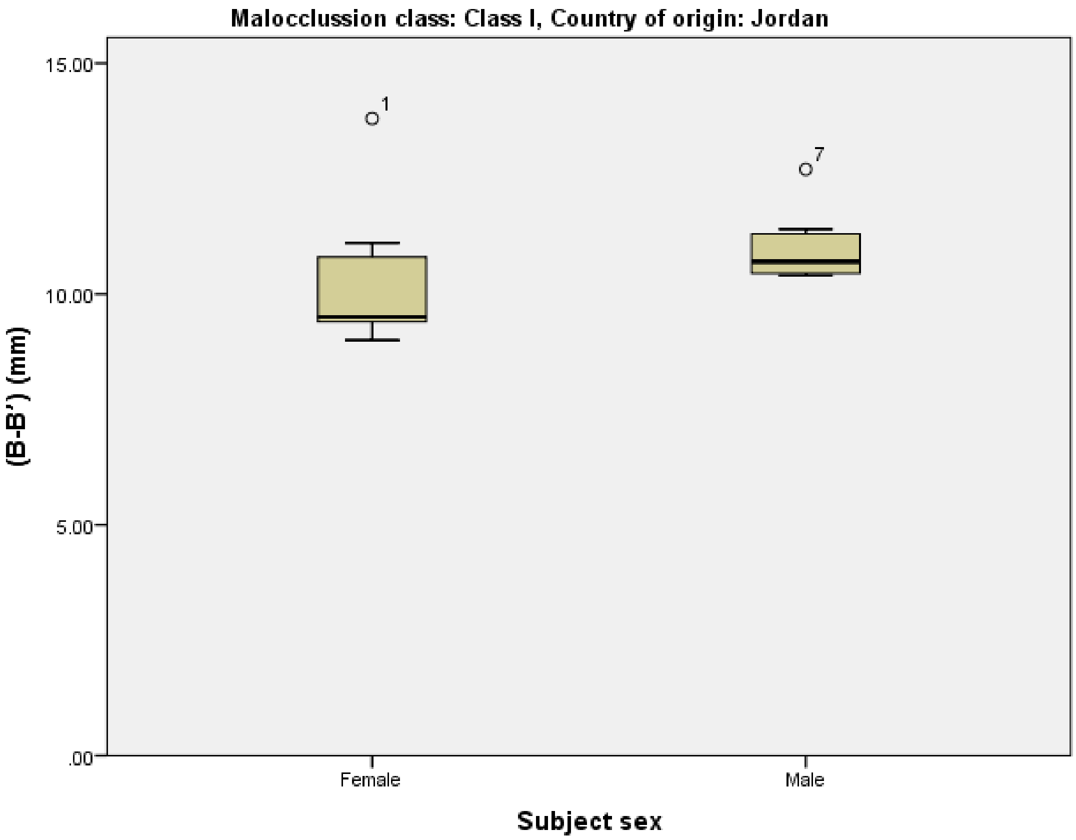

Malocclussion class: Class II div 1, Country of origin: Scotland
60.00
50.00
40.00
30.00
20.00
10.00
.00
(Sti-Me') (mm)
Female
Male
Subject sex

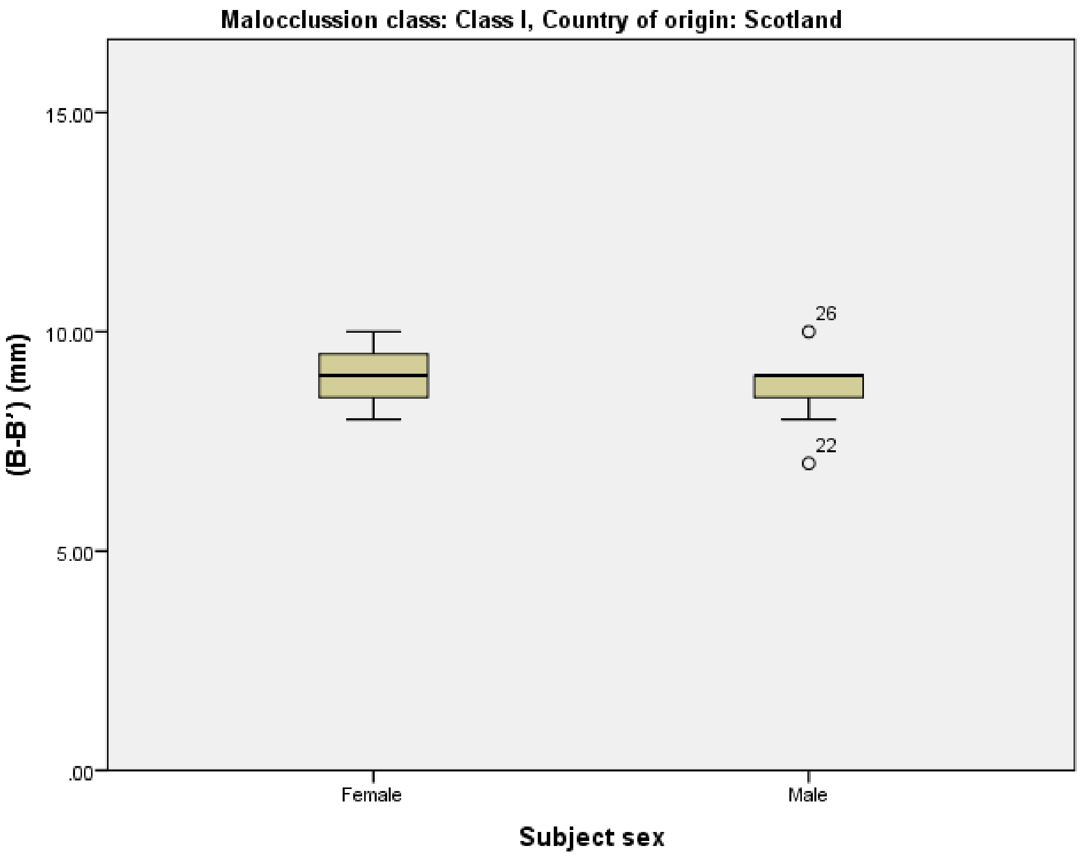

Malocclussion class: Class II div 2, Country of origin: Jordan
60.00
50.00
40.00
30.00
20.00
10.00
.00
(Sti-Me') (mm)
Female
Male
Subject sex

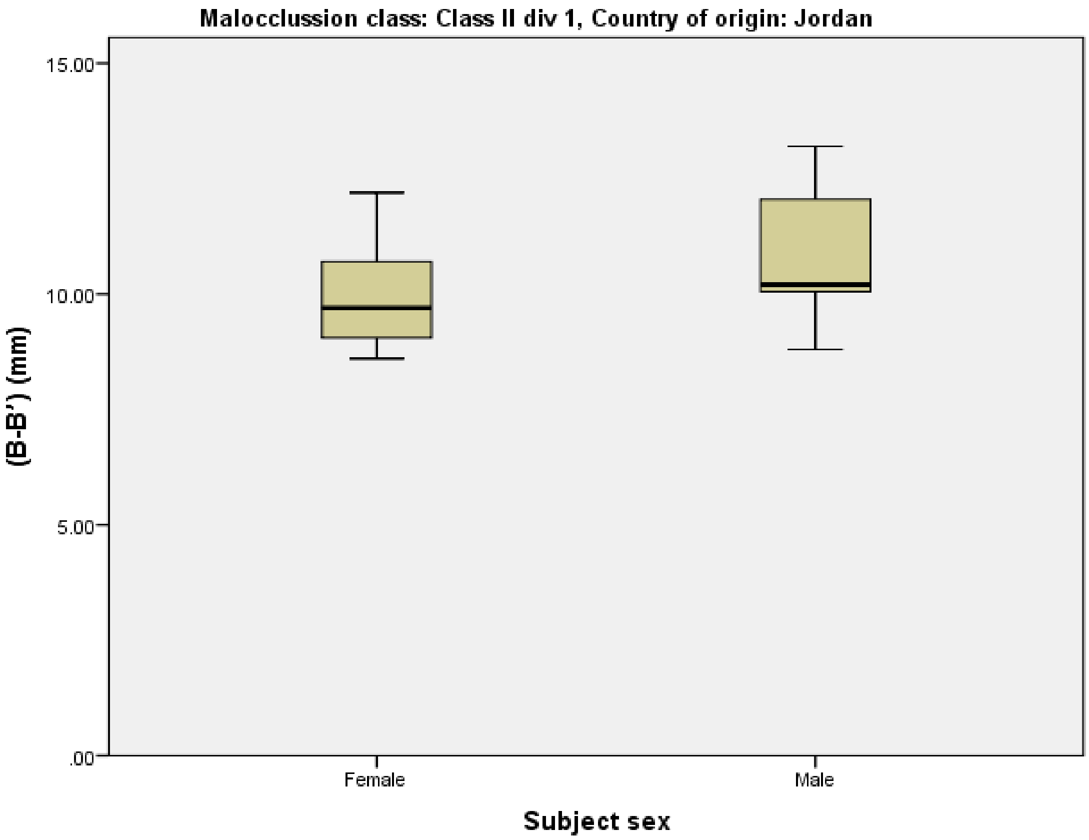

Malocclussion class: Class II div 2, Country of origin: Scotland
60.00
50.00
40.00
30.00
20.00
10.00
.00
(Sti-Me') (mm)
Female
Male
Subject sex

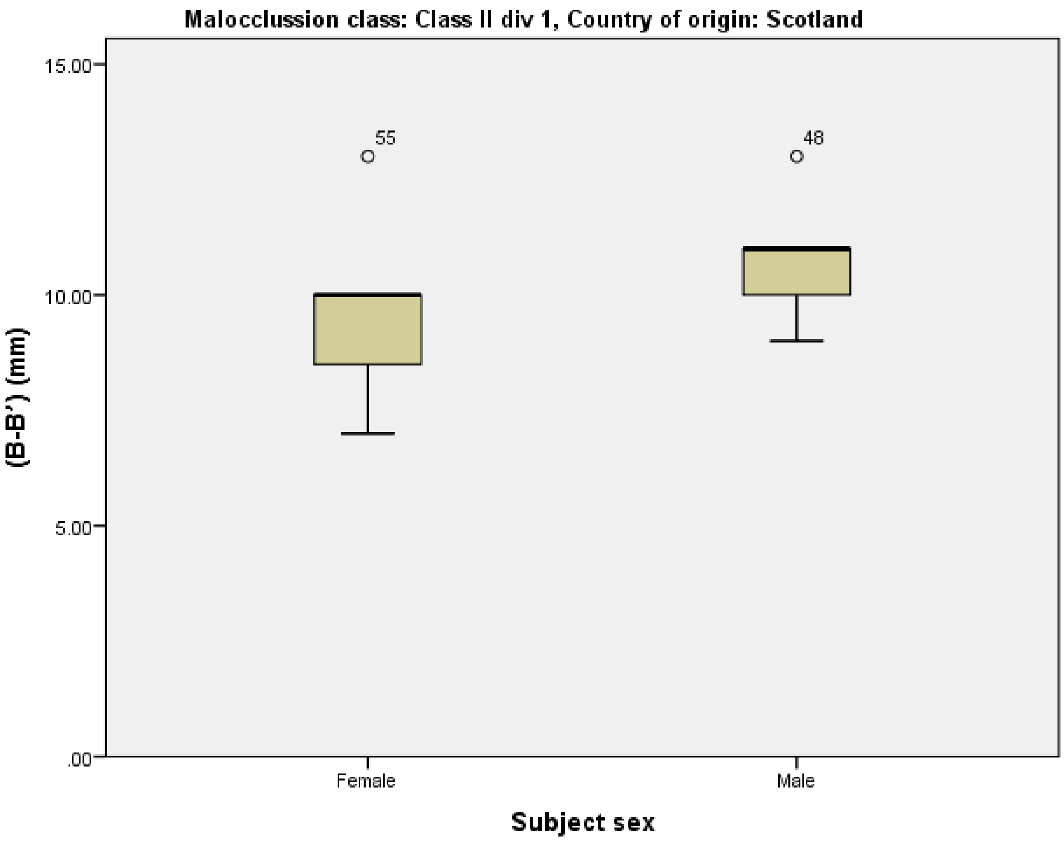

Malocclussion class: Class III, Country of origin: Jordan
(Sti-Me') (mm)
60.00
50.00
40.00
30.00
20.00
10.00
.00
Female
Male
Subject sex

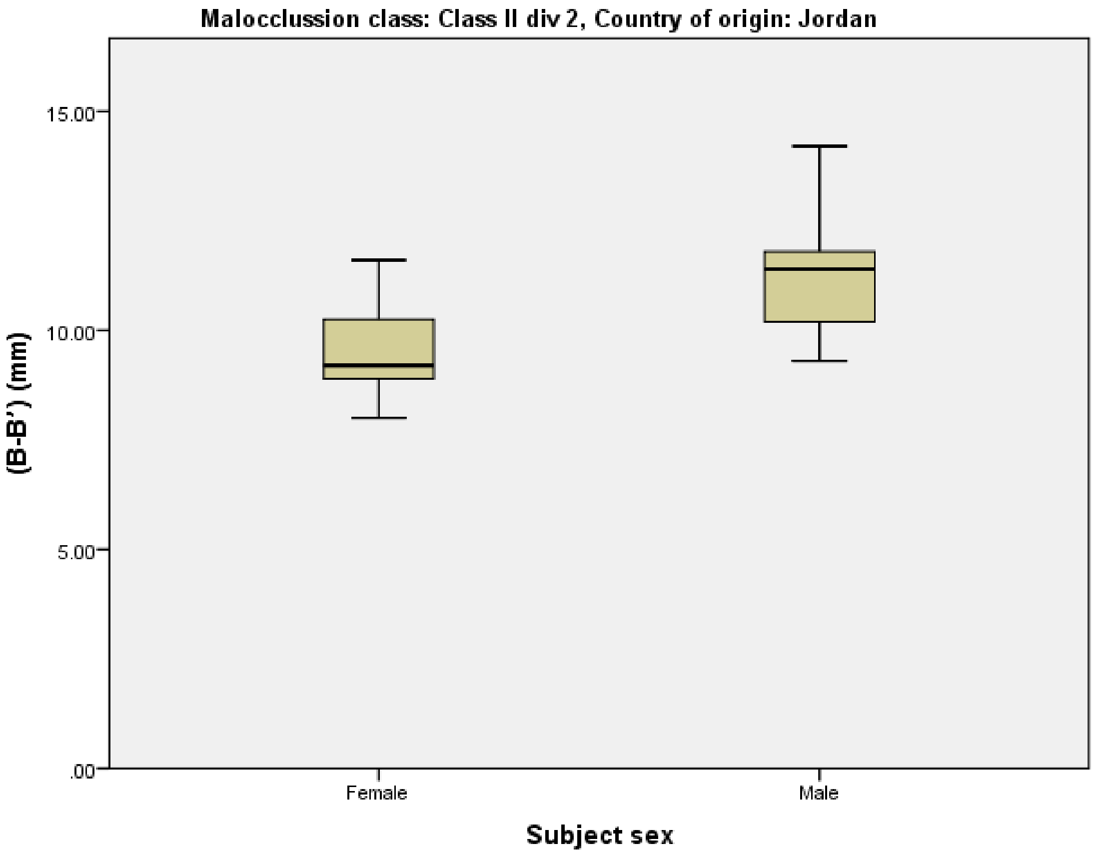

Malocclussion class: Class III, Country of origin: Scotland
(Sti-Me') (mm)
60.00
50.00
40.00
30.00
20.00
10.00
.00
Female
Male
Subject sex

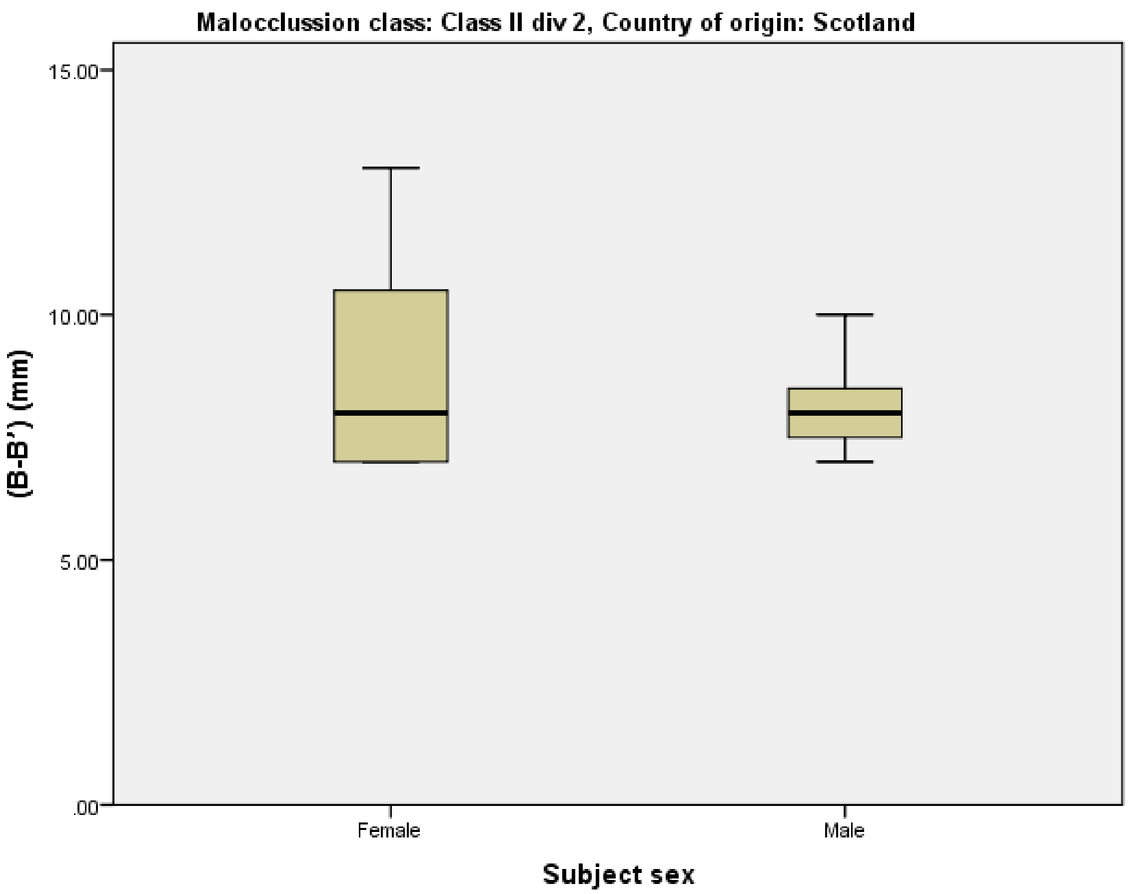

Malocclussion class: Class I, Country of origin: Jordan
15.00
10.00
5.00
.00
(B-B') (mm)
1
7
Female
Male
Subject sex

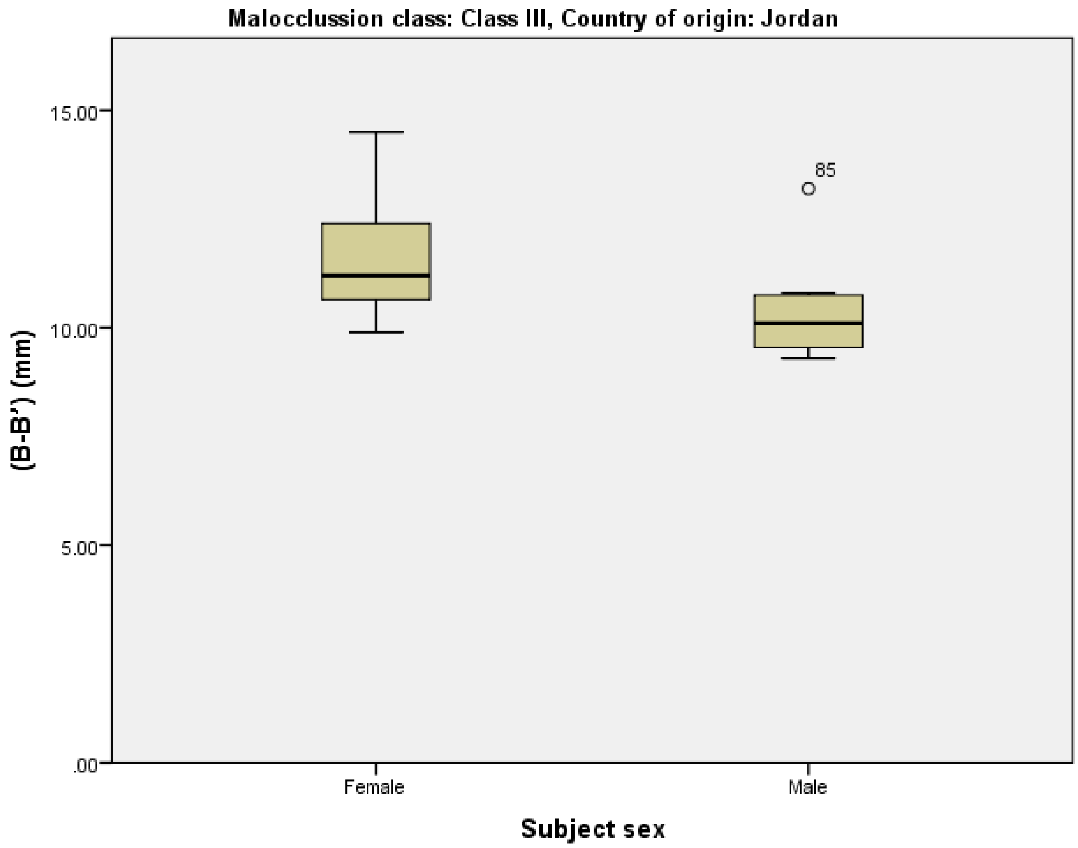

Malocclussion class: Class I, Country of origin: Scotland
15.00
10.00
5.00
.00
(B-B') (mm)
26
22
Female
Male
Subject sex

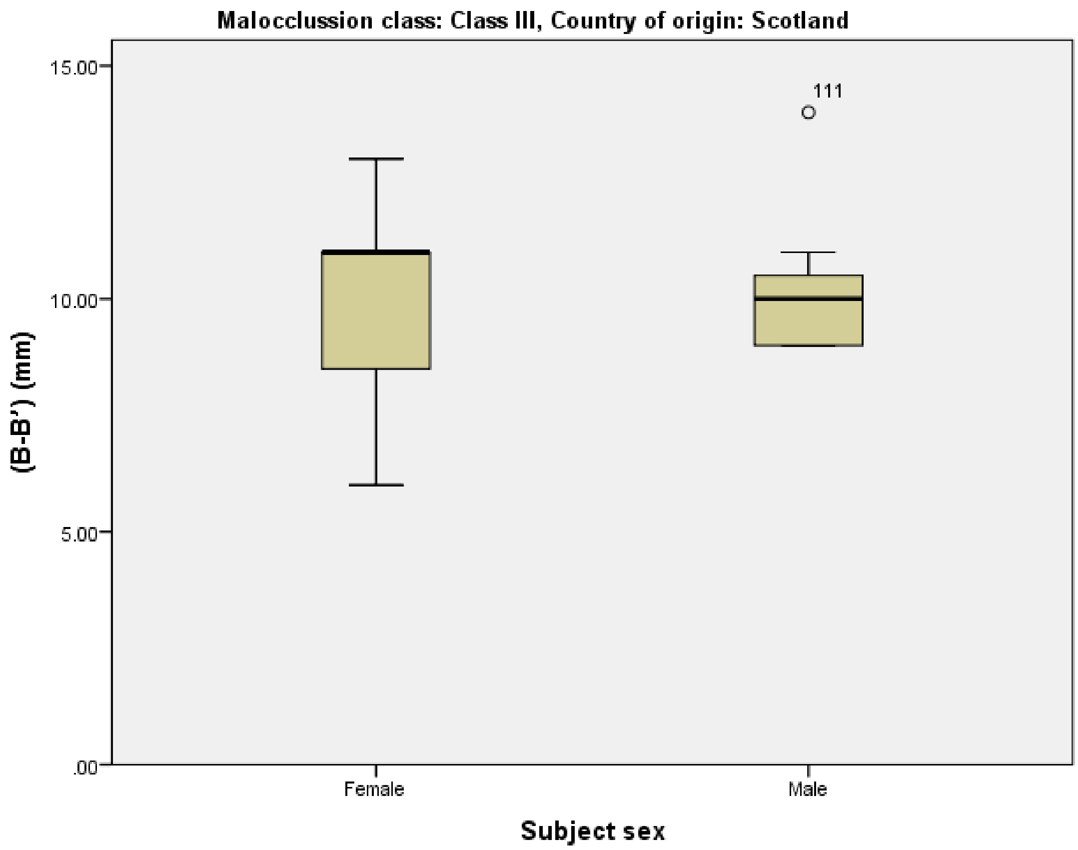

Malocclussion class: Class II div 1, Country of origin: Jordan
15.00
10.00
5.00
.00
(B-B') (mm)
Female
Male
Subject sex

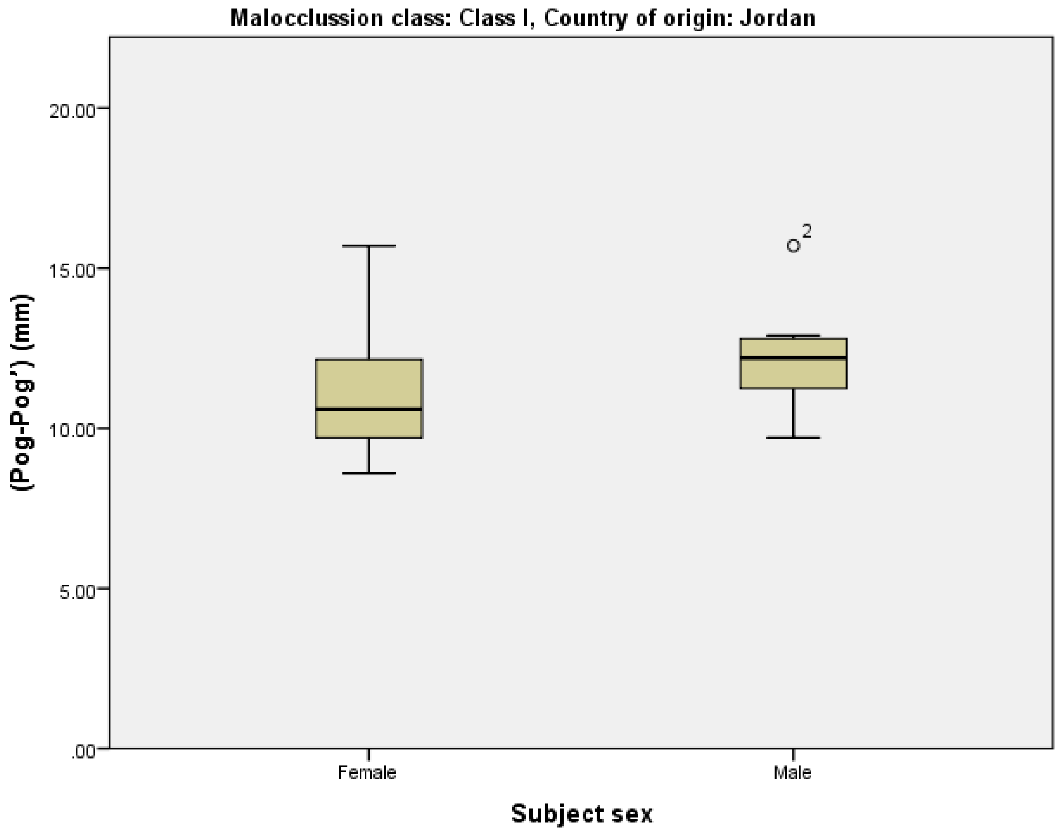

Malocclussion class: Class II div 1, Country of origin: Scotland
15.00
10.00
5.00
.00
(B-B') (mm)
55
48
Female
Male
Subject sex

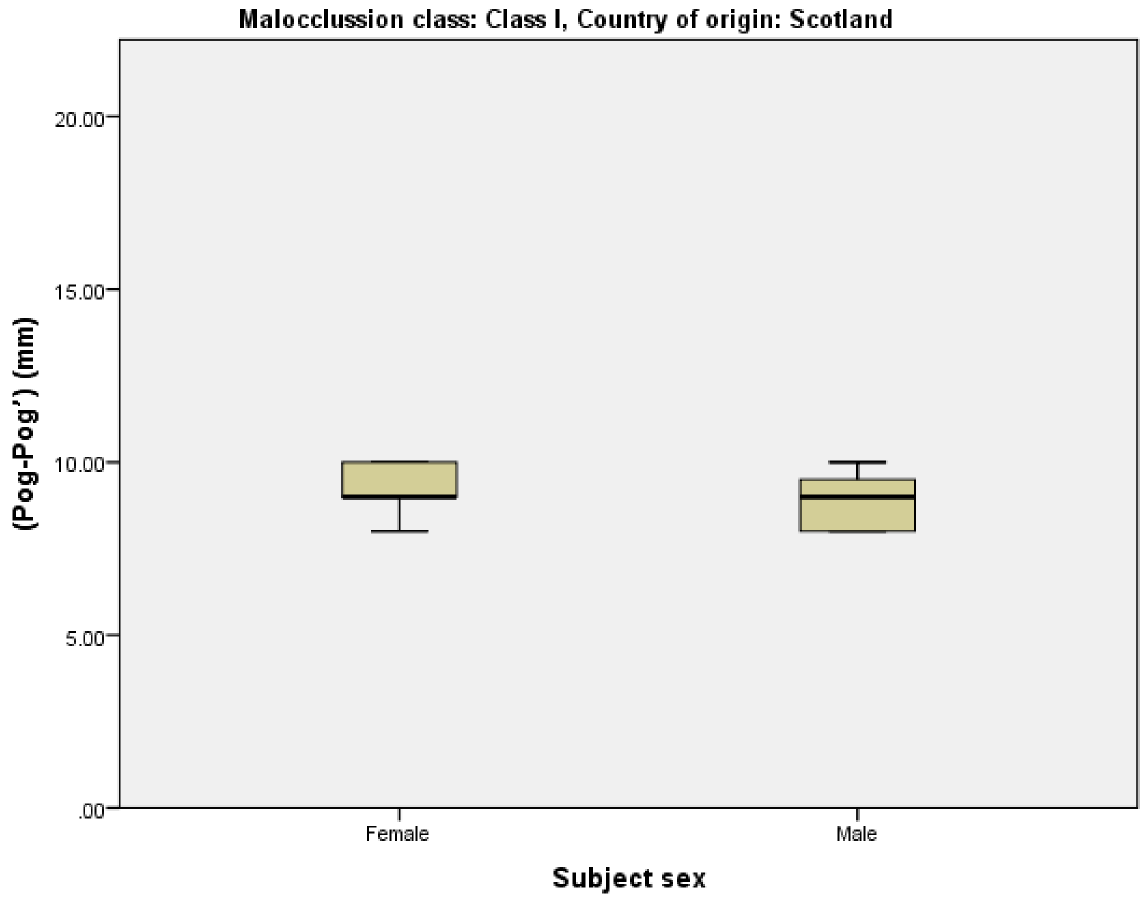

Malocclussion class: Class II div 2, Country of origin: Jordan
15.00
10.00
5.00
.00
(B-B') (mm)
Female
Male
Subject sex

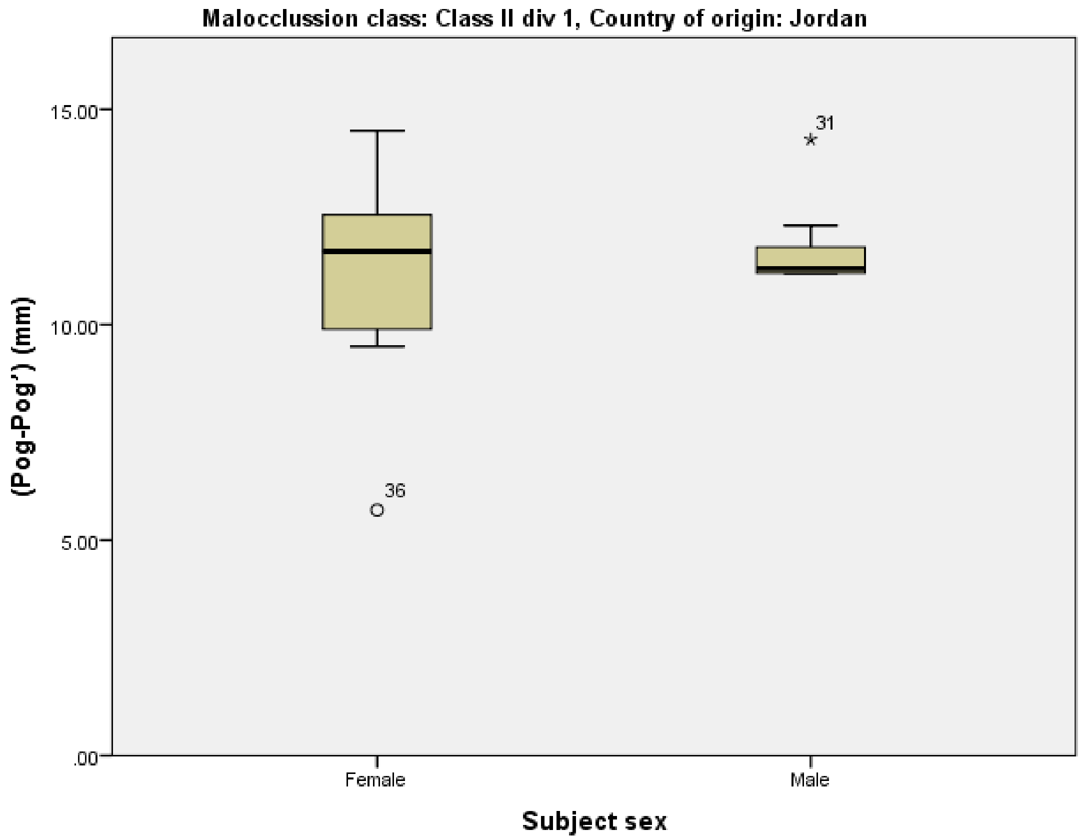

Malocclussion class: Class II div 2, Country of origin: Scotland
15.00
10.00
5.00
.00
(B-B') (mm)
Female
Male
Subject sex

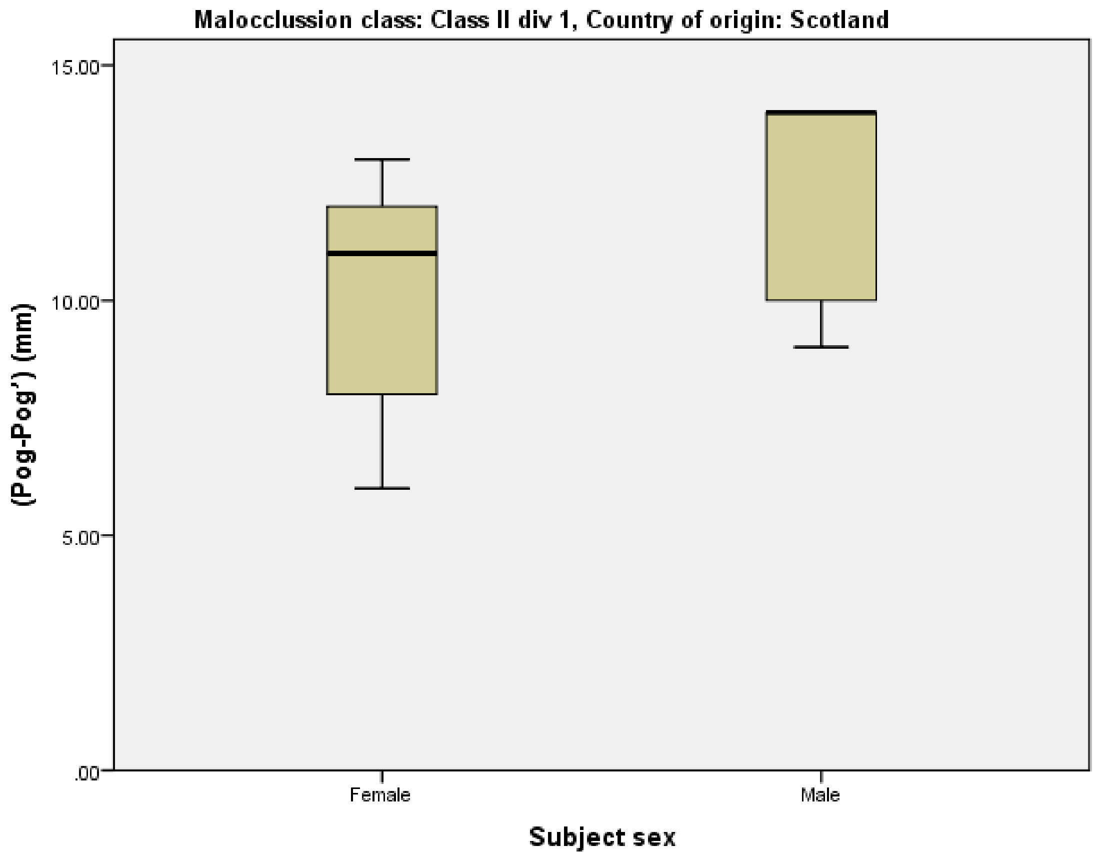

Malocclussion class: Class III, Country of origin: Jordan
15.00
10.00
5.00
.00
(B-B') (mm)
85
Female
Male
Subject sex

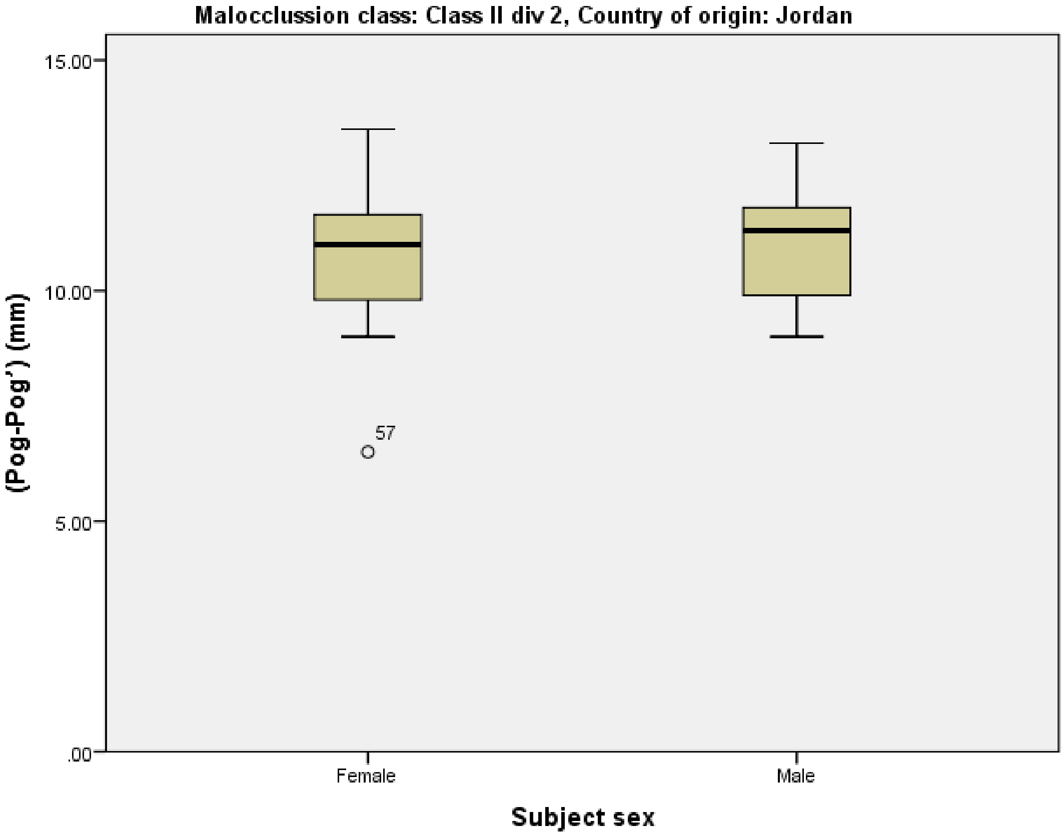

Malocclussion class: Class III, Country of origin: Scotland
15.00
10.00
5.00
.00
(B-B') (mm)
111
Female
Male
Subject sex

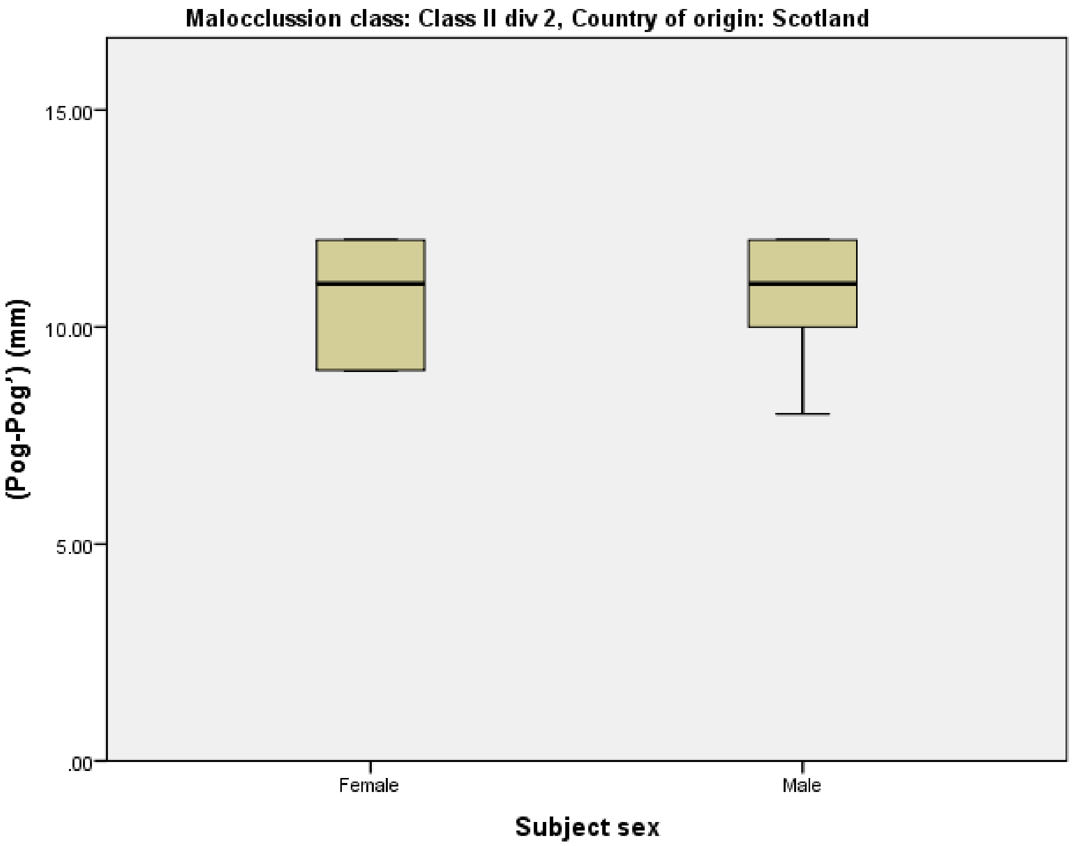

Malocclussion class: Class I, Country of origin: Jordan
20.00
15.00
10.00
5.00
.00
(Pog-Pog') (mm)
2
Female
Male
Subject sex

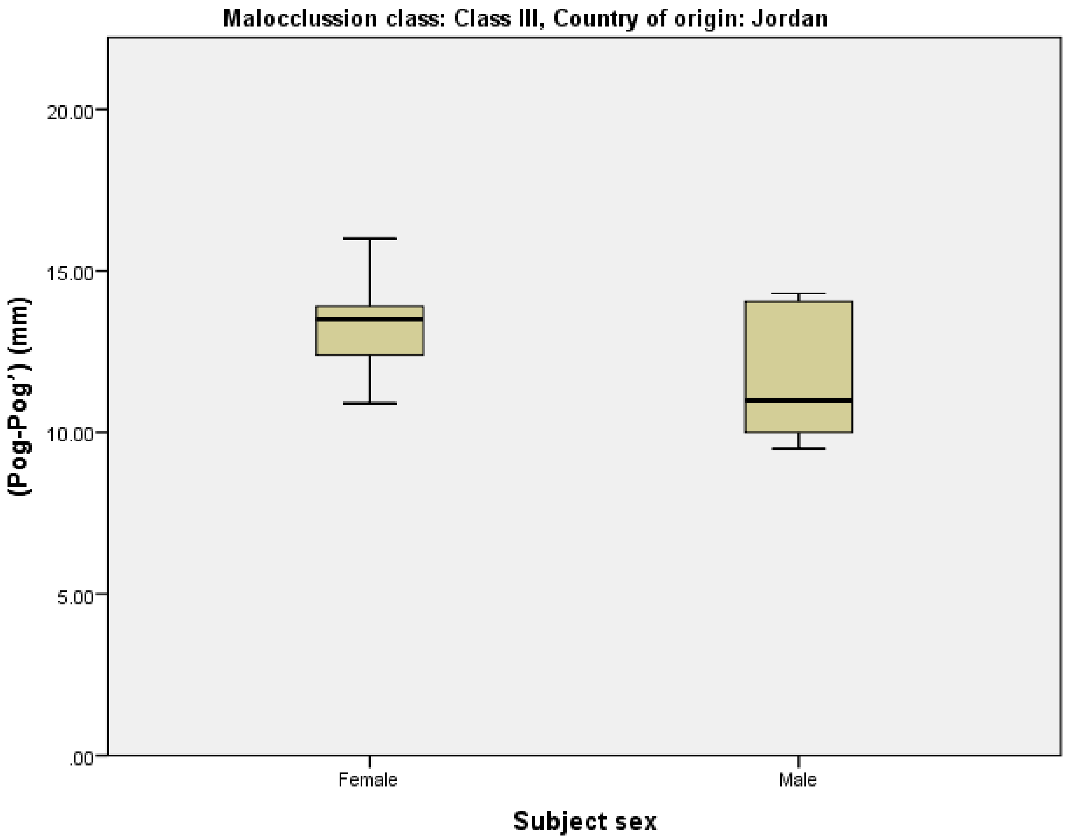

Malocclussion class: Class I, Country of origin: Scotland
20.00
15.00
10.00
5.00
.00
(Pog-Pog') (mm)
Female
Male
Subject sex

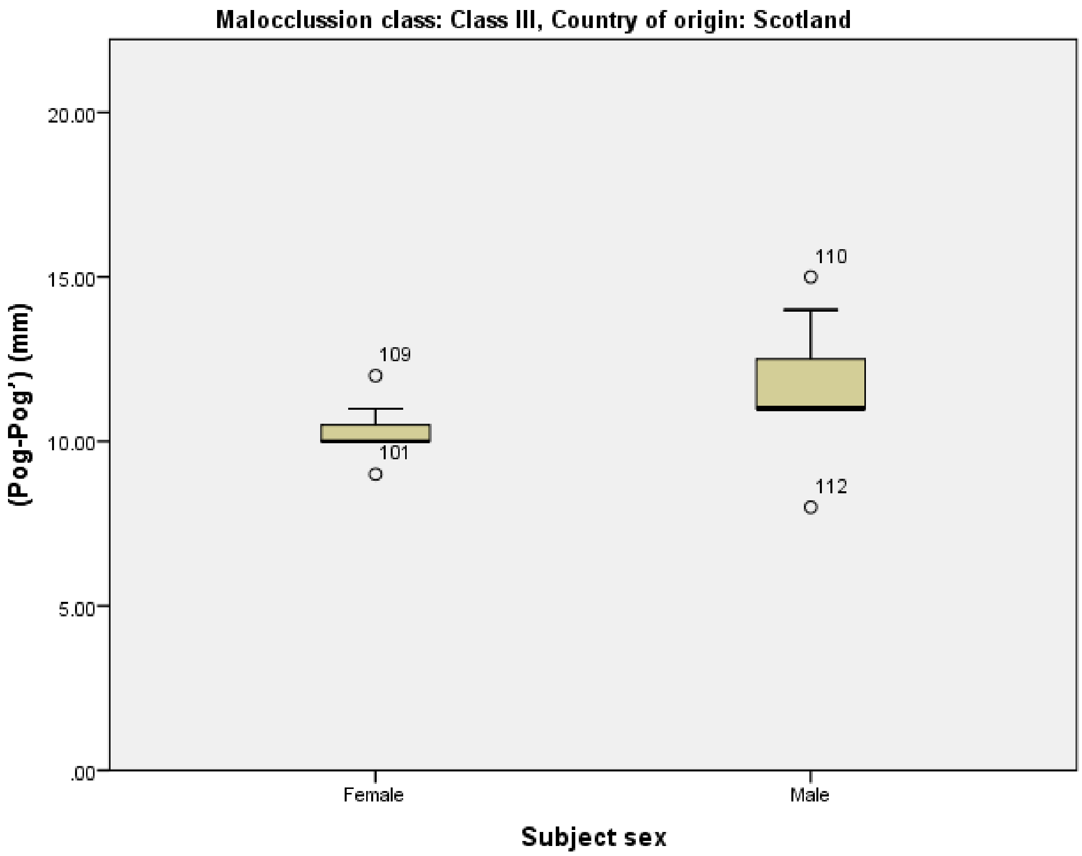

Malocclussion class: Class II div 1, Country of origin: Jordan
15.00
10.00
5.00
.00
31
36
(Pog-Pog') (mm)
Female
Male
Subject sex


Malocclussion class: Class II div 1, Country of origin: Scotland
15.00
10.00
5.00
.00
(Pog-Pog') (mm)
Female
Male
Subject sex


Malocclussion class: Class II div 2, Country of origin: Jordan
15.00
10.00
5.00
.00
(Pog-Pog') (mm)
57
Female
Male
Subject sex


Malocclussion class: Class II div 2, Country of origin: Scotland
15.00
10.00
5.00
.00
(Pog-Pog') (mm)
Female
Male
Subject sex


Malocclussion class: Class III, Country of origin: Jordan
(Pog-Pog') (mm)
20.00
15.00
10.00
5.00
.00
Female
Male
Subject sex


Malocclussion class: Class III, Country of origin: Scotland
(Pog-Pog') (mm)
20.00
15.00
10.00
5.00
.00
109
101
110
112
Female
Male
Subject sex

Appendix III

Reliability Results/ Cephalogram analysis

Class I/ The Wilcoxon signed-rank test results

Cephalogram variable	Jordan				Scotland			
	Median investigator	Median Observer1	Median Observer2	p level	Median investigator	Median Observer1	Median Observer2	p level
N'-Pr-Pog'	128.90	129.70	129.10	0.61	132.00	131.00	130.00	0.34
N'-Sn-Pog'	159.75	159.00	160.70	0.78	162.50	162.53	162.55	0.89
CM-Sn-Ls	109.30	102.65	106.10	0.55	111.00	110.00	111.00	0.54
N-A-Pog	7.60	7.55	7.10	0.45	5.00	6.00	5.00	0.56
ANB	1.55	1.57	1.60	0.78	2.85	2.75	2.80	0.45
SNA	81.05	81.04	81.08	0.97	80.25	80.15	80.29	0.23
SNB	79.25	79.27	79.30	0.34	77.55	77.50	76.05	0.45
MMPA	22.05	22.08	22.09	0.89	27.90	27.80	27.91	0.78
UI/MX	112.55	112.57	112.56	0.54	109.40	109.40	109.40	0.97
LI/MP	95.45	96.10	95.42	0.56	91.25	91.15	91.20	0.34
UI/LI	128.10	127.99	128.07	0.45	131.70	131.71	131.74	0.89
TFH	106.70	106.72	106.73	0.23	109.65	109.61	109.60	0.54
UAFH	47.50	47.47	47.46	0.34	49.75	49.75	49.72	0.56
LAFH	58.45	58.42	58.43	0.45	60.90	59.79	61.54	0.61
PFH	72.20	72.21	72.19	0.56	69.90	70.09	69.87	0.78
Sts-Sn	19.05	18.76	16.60	0.54	20.00	20.00	19.00	0.55
A-A'	12.40	13.10	11.40	0.89	13.00	13.00	12.00	0.78
Pr-A'	16.85	16.05	16.30	0.65	20.50	21.50	23.50	0.34
Sti-Me'	43.75	40.40	44.40	0.66	40.00	42.00	41.00	0.34
B-B'	10.50	10.45	10.52	0.34	9.00	10.00	9.00	0.56
Pog-Pog'	11.70	11.70	11.40	0.43	9.00	9.00	8.00	0.78

***Table III-1**: Wilcoxon signed-rank test, non-parametric test, results used as an alternative to the paired t-test to show the agreement between raters. The median values of the cephalogram parameters also displayed.*

Class II div 1/ The Wilcoxon signed-rank test results

Cephalogram	Jordan	Scotland

variable	Median investigator	Median Observer1	Median Observer2	p level Wilcoxon	Median investigator	Median Observer1	Median Observer2	p level Wilcoxon
N’-Pr-Pog’	130.05	130.15	132.44	0.77	126.00	126.00	126.00	0.97
N’-Sn-Pog’	157.15	157.13	157.17	0.94	153.00	153.00	153.00	0.34
CM-Sn-Ls	108.50	109.50	108.46	0.45	109.50	109.54	110.00	0.89
N-A-Pog	7.60	8.60	6.60	0.23	8.00	9.00	7.00	0.54
ANB	7.40	7.47	7.42	0.34	4.00	6.00	7.00	0.56
SNA	82.60	83.60	82.65	0.45	84.00	82.00	84.00	0.61
SNB	75.70	75.70	74.09	0.56	80.00	83.00	84.00	0.78
MMPA	31.55	33.20	31.05	0.54	31.50	31.55	31.56	0.55
UI/MX	121.55	121.58	121.65	0.97	111.00	112.00	115.00	0.45
LI/MP	101.50	102.50	101.53	0.34	91.00	90.00	91.00	0.56
UI/LI	116.90	116.91	116.54	0.89	121.50	121.54	121.51	0.54
TFH	105.10	105.11	105.13	0.54	107.39	106.29	107.30	0.78
UAFH	46.85	45.34	47.05	0.56	44.17	44.19	44.54	0.89
LAFH	60.65	61.15	62.22	0.61	59.82	59.76	59.90	0.45
PFH	64.65	64.25	64.45	0.78	63.20	63.25	63.27	0.78
Sts-Sn	18.30	18.34	18.32	0.55	20.00	23.00	21.00	0.97
A-A’	11.90	10.90	11.56	0.45	14.00	13.00	15.00	0.97
Pr-A’	14.45	14.05	14.39	0.97	15.00	13.00	16.00	0.89
Sti-Me’	38.20	38.18	38.23	0.34	41.00	42.00	43.00	0.54
B-B’	10.15	10.18	10.25	0.54	10.00	9.00	11.00	0.61
Pog-Pog’	11.30	11.33	11.36	0.45	11.00	12.00	10.00	0.55

Table III-2: *Wilcoxon signed-rank test, non-parametric test, results used as an alternative to the paired t-test to show the agreement between raters. The median values of the cephalogram parameters also displayed.*

Class II div 2/ *Wilcoxon signed-rank*

Cephalogram variable	Jordan				Scotland			
	Median investigator	Median Observer1	Median Observer2	p level Wilcoxon	Median investigator	Median Observer1	Median Observer2	p level Wilcoxon
N'-Pr-Pog'	129.90	129.92	129.78	0.75	130.50	131.00	132.00	0.45
N'-Sn-Pog'	158.15	157.15	158.55	0.94	160.50	160.00	161.50	0.78
CM-Sn-Ls	107.55	107.25	107.43	0.48	119.00	117.00	117.00	0.97
N-A-Pog	7.70	7.73	7.17	0.54	6.00	5.50	5.00	0.34
ANB	5.00	5.15	5.67	0.86	4.50	4.50	4.50	0.89
SNA	78.95	78.55	79.05	0.45	84.00	83.00	84.00	0.54
SNB	73.60	73.62	73.64	0.75	80.00	83.00	81.00	0.56
MMPA	29.05	29.55	29.15	0.56	22.00	20.00	23.00	0.45
UI/MX	110.50	110.53	110.48	0.71	84.00	83.00	85.00	0.45
LI/MP	94.45	94.78	94.50	0.34	87.00	86.00	85.00	0.56
UI/LI	125.40	125.13	125.56	0.89	151.00	150.00	154.00	0.54
TFH	109.30	105.66	108.00	0.54	108.16	108.00	108.11	0.78
UAFH	46.45	44.98	44.77	0.56	47.98	47.92	47.90	0.89
LAFH	61.40	62.42	61.40	0.61	57.75	57.70	57.71	0.45
PFH	66.05	66.08	66.87	0.78	74.13	74.14	74.10	0.97
Sts-Sn	19.30	19.32	19.37	0.34	21.50	22.00	21.00	0.34
Sts/ANS-PNS	22.30	22.25	22.35	0.89	25.00	22.00	23.00	0.89
A-A'	11.05	11.22	11.01	0.59	14.00	15.00	15.00	0.54
Pr-A'	14.30	14.32	14.25	0.63	16.00	16.00	17.00	0.61
Sti-Me'	39.80	39.82	38.83	0.98	46.00	43.00	45.00	0.78
Sti/Me-GO	41.00	41.06	41.07	0.55	42.00	43.00	41.00	0.55
B-B'	10.20	10.23	10.25	0.97	8.00	8.00	7.00	0.97
Pog-Pog'	11.15	10.50	11.00	0.56	11.00	10.00	11.00	0.89

Table III-3: *Wilcoxon signed-rank test, non-parametric test, results used as an alternative to the paired t-test to show the agreement between raters. The median values of the cephalogram parameters also displayed.*

Class III/ *Wilcoxon signed-rank test result*

Cephalogram variable	Jordan				Scotland			
	Median investigator	Median Observer1	Median Observer2	p level Wilcoxon	Median investigator	Median Observer1	Median Observer2	p level Wilcoxon
N'-Pr-Pog'	133.25	132.20	131.25	0.75	132.00	130.00	130.00	0.45
N'-Sn-Pog'	162.75	162.50	162.90	0.94	167.00	165.00	163.00	0.78
CM-Sn-Ls	4.40	3.96	4.50	0.48	99.00	98.00	99.50	0.97
N-A-Pog	99.05	98.50	98.95	0.54	4.00	4.50	3.00	0.34
ANB	1.65	1.75	1.50	0.86	3.50	3.00	4.00	0.89
SNA	82.10	82.30	82.50	0.45	93.00	91.00	92.00	0.54
SNB	80.05	81.15	80.50	0.75	89.50	89.25	89.00	0.56
MMPA	35.00	35.15	34.50	0.56	26.00	26.50	25.00	0.45
UI/MX	113.80	112.64	113.50	0.71	106.00	103.00	105.00	0.45
LI/MP	92.70	92.50	92.75	0.34	74.00	73.00	73.00	0.56
UI/LI	120.10	120.23	120.00	0.89	150.00	151.00	153.00	0.54
TFH	107.20	107.40	107.00	0.54	107.07	107.00	107.15	0.78
UAFH	45.35	45.50	45.25	0.56	43.16	43.50	43.00	0.89
LAFH	64.45	65.50	64.56	0.61	63.08	63.50	63.00	0.45
PFH	66.05	66.00	66.15	0.78	67.66	67.16	67.00	0.97
Sts-Sn	19.30	18.20	19.50	0.34	18.50	18.50	18.00	0.34
Sts/ANS-PNS	24.65	25.50	24.85	0.89	23.00	22.00	23.00	0.89
A-A'	11.75	11.50	11.25	0.59	18.00	19.00	18.00	0.54
Pr-A'	14.15	14.35	14.05	0.63	18.00	20.00	19.00	0.61
Sti-Me'	39.40	39.45	39.47	0.98	4.50	4.00	4.00	0.78
Sti/Me-GO	44.55	44.00	44.65	0.55	14.00	13.00	12.00	0.55
B-B'	10.75	10.58	10.25	0.97	47.50	45.50	47.00	0.97
Pog-Pog'	13.20	13.00	13.25	0.56	11.00	10.00	12.00	0.89

Table III-4: *Wilcoxon signed-rank test, non-parametric test, results used as an alternative to the paired t-test to show the agreement between raters. The median values of the cephalogram parameters also displayed.*

Reliability Analysis/ morphological analysis

Scottish Sample

Morphological Traits	Intra-observer reliability (Cronbach's Alpha)				Inter-observer reliability (Cronbach's Alpha)			
	I	II /1	II/2	III	I	II/1	II/2	III
Philtrum shape	1.00	0.91	0.92	0.96	0.99	0.98	0.99	0.98
Cupid's bow shape	1.00	0.91	0.96	1.00	0.94	0.89	0.94	0.97
Upper lip Vermillion fullness	1.00	1.00	1.00	1.00	0.86	0.98	0.93	1.00
Lower lip Vermillion fullness	0.93	0.99	1.00	0.85	0.98	1.00	0.99	0.93
Upper Vermillion border Contour	0.94	0.91	0.94	1.00	0.94	1.00	0.94	0.99
Commissures	1.00	0.98	0.97	0.91	0.93	0.97	0.90	0.90

***Table III-5**: Inter- and intra-observers internal consistency reliability results for the Scottish sample.*

Jordanian Sample

Morphological Traits	Intra-examiner agreement (Intra) (Cronbach's Alpha)				Inter-examiner agreement (Cronbach's Alpha)			
	I	II /1	II/2	III	I	II/1	II/2	III
Philtrum shape	0.91	1.00	1.00	1.00	0.84	0.90	1.00	1.00
Cupid's bow shape	1.00	0.93	1.00	1.00	1.00	0.88	1.00	0.79
Upper lip vermillion fullness	1.00	0.95	0.90	1.00	1.00	0.93	0.89	0.89
Lower lip vermillion fullness	1.00	0.92	0.92	1.00	1.00	0.86	0.87	0.79
Commissures	1.00	1.00	0.92	1.00	1.00	0.87	0.87	1.00

***Table III-6:** Inter- and intra-observers internal consistency reliability results for the Jordanian sample.*

Appendix IV

Cephalogram Analysis Results

	Country of origin	Mean	Std. Deviation	Sig. (2-tailed)
(N'-Pr-Pog').	Jordan	131.2750	5.47175	
	Scotland	131.1964	5.27919	.939
Angle of soft tissue convexity without the nose (N'-Sn-Pog')	Jordan	159.2339	5.95282	
	Scotland	160.9464	6.63988	.154
Nasolabial angle (CM-Sn-Ls).	Jordan	105.2054	10.56933	
	Scotland	113.6429	13.58934	.000
ANB	Jordan	4.4679	3.01711	
	Scotland	3.9268	2.23000	.283
SNA	Jordan	81.4696	3.60343	
	Scotland	85.1893	4.79646	.000
SNB	Jordan	77.1679	4.29359	
	Scotland	81.3393	5.17324	.000
MMPA	Jordan	28.4946	7.45648	
	Scotland	27.6179	4.22925	.446
UI/MX	Jordan	130.8732	133.91693	
	Scotland	103.5464	10.18009	.131
LI/MP	Jordan	94.5446	7.53836	
	Scotland	86.2714	6.88360	.000
UI/LI	Jordan	123.8214	10.56037	
	Scotland	139.5107	14.75590	.000
Total anterior facial height	Jordan	108.4071	6.55877	
	Scotland	107.5886	4.50909	.443
Upper anterior facial height	Jordan	46.6411	3.86032	
	Scotland	46.4861	3.76795	.830
Lower facial height	Jordan	61.8429	5.70690	
	Scotland	60.9864	3.90428	.356
Posterior facial height	Jordan	67.5714	6.26078	
	Scotland	68.4898	4.67607	.381
Upper lip length from subnasale (Sts-Sn)	Jordan	19.4393	2.81313	
	Scotland	20.0179	2.75345	.274
Upper lip thickness at the base of the skull (A-A')	Jordan	12.0286	2.28152	
	Scotland	15.4286	3.25776	.000
Nose depth (Pr-A')	Jordan	15.0732	2.86759	
	Scotland	16.5714	4.73999	.045
Lower lip length from soft	Jordan	40.2929	5.07098	

tissue menton point (Sti-Me').	Scotland	42.6786	5.27122	.016
Lower lip thickness at B-point (B-B')	Jordan	10.6661	1.47405	
	Scotland	9.4107	1.79673	.000
Soft tissue chin thickness (Pog-Pog')	Jordan	11.6179	2.08764	
	Scotland	10.4286	1.98958	0.003

Table IV-1: comparison between Jordanian (n= 56) and Scottish (56)

	Subject sex	Mean	Std. Deviation	Sig. (2-tailed)
(N'-Pr-Pog')(Degree)	Female	132.4000	5.51566	
	Male	130.0714	4.96287	.021
(N'-Sn-Pog')(Degree)	Female	160.8286	5.82389	
	Male	159.3518	6.78153	.219
(CM-Sn-Ls) (Degree)	Female	108.6893	11.33823	
	Male	110.1589	14.24671	.547
ANB (Degree)	Female	3.7446	2.21720	
	Male	4.6500	2.98188	.071
SNA (Degree)	Female	82.5500	4.74763	
	Male	84.1089	4.38830	.074
SNB (Degree)	Female	78.9268	5.39196	
	Male	79.5804	4.97647	.506
MMPA (Degree)	Female	27.8232	6.27381	
	Male	28.2893	5.86564	.685
UI/MX (Degree)	Female	127.1857	134.48058	
	Male	107.2339	11.39578	.271
LI/MP (Degree)	Female	90.0911	9.40768	
	Male	90.7250	7.09556	.688
UI/LI (Degree)	Female	131.3964	14.78673	
	Male	131.9357	15.35504	.850
Total anterior facial height (mm)	Female	107.0777	5.36388	
	Male	108.9180	5.76150	.083
Upper anterior facial height (mm)	Female	45.6298	3.57740	
	Male	47.4973	3.81294	.009
Lower facial height (mm)	Female	61.2634	4.97759	
	Male	61.5659	4.83347	.745
Posterior facial height (mm)	Female	67.3563	5.33267	
	Male	68.7050	5.66823	.197
(Sts-Sn) (mm)	Female	19.4893	2.61525	
	Male	19.9679	2.95119	.366
(A-A') (mm)	Female	12.8143	2.48511	
	Male	14.6429	3.71825	.003

(Pr-A') (mm)	Female	15.4732	4.01123	
	Male	16.1714	3.93639	.355
(Sti-Me') (mm)	Female	40.9804	5.26182	
	Male	41.9911	5.30955	.314
(B-B') (mm)	Female	9.8839	1.84871	
	Male	10.1929	1.65440	.353
(Pog-Pog') (mm)	Female	10.7732	2.22429	
	Male	11.2732	1.99048	.213

Table IV-2: comparison between females (n=56) and males (n= 56)

ANOVA Results

				95% Confidence Interval for Mean		Sig
		Mean	Std. Deviation	Lower Bound	Upper Bound	
(N'-Pr-Pog')(Degree)	Class I	131.1	3.2	129.8	132.3	0.003
	Class II div 1	128.8	5.4	126.7	130.9	
	Class II div 2	131.1	5.2	129.1	133.1	
	Class III	134.0	6.1	131.6	136.4	
	Total	131.2	5.4	130.2	132.2	
(N'-Sn-Pog')(Degree)	Class I	160.6	4.2	158.9	162.2	0.000
	Class II div 1	155.3	5.9	153.0	157.6	
	Class II div 2	160.6	5.1	158.6	162.6	
	Class III	163.9	6.9	161.2	166.6	
	Total	160.1	6.3	158.9	161.3	
(CM-Sn-Ls) (Degree)	Class I	109.7	7.2	106.9	112.5	0.048
	Class II div 1	113.1	15.2	107.3	119.0	
	Class II div 2	110.9	13.3	105.8	116.0	
	Class III	104.0	13.2	98.9	109.1	
	Total	109.4	12.8	107.0	111.8	
UI/MX (Degree)	Class I	109.8	5.7	107.6	112.0	0.000
	Class II div 1	114.8	6.8	112.1	117.4	

	Class II div 2	98.3	12.8	93.4	103.3	
	Class III	110.2	7.7	107.2	113.2	
	Total	108.3	10.5	106.3	110.2	
LI/MP (Degree)	Class I	93.1	3.9	91.6	94.6	0.000
	Class II div 1	94.8	7.8	91.8	97.8	
	Class II div 2	90.1	6.2	87.6	92.5	
	Class III	83.6	9.7	79.9	87.4	
	Total	90.4	8.3	88.9	92.0	
UI/LI (Degree)	Class I	130.7	3.9	129.2	132.3	0.000
	Class II div 1	117.7	6.7	115.2	120.3	
	Class II div 2	143.8	16.6	137.4	150.3	
	Class III	134.4	15.1	128.5	140.2	
	Total	131.7	15.0	128.9	134.5	
Total anterior facial height (mm)	Class I	108.3	3.8	106.8	109.8	0.765
	Class II div 1	107.5	7.3	104.7	110.4	
	Class II div 2	108.8	5.8	106.5	111.0	
	Class III	107.4	5.3	105.3	109.4	
	Total	108.0	5.6	106.9	109.0	
Upper anterior facial height (mm)	Class I	48.4	2.0	47.6	49.2	0.000
	Class II div 1	46.2	3.9	44.7	47.7	
	Class II div 2	47.7	3.5	46.4	49.1	
	Class III	43.9	3.9	42.4	45.4	
	Total	46.6	3.8	45.9	47.3	
Lower facial height (mm)	Class I	60.5	3.0	59.4	61.6	0.179
	Class II div 1	61.0	6.2	58.6	63.3	
	Class II div 2	61.1	5.7	58.8	63.3	
	Class III	63.1	3.8	61.7	64.6	
	Total	61.4	4.9	60.5	62.3	
(Sts-Sn) (mm)	Class I	19.4	1.6	18.8	20.0	0.427

	Class II div 1	19.4	2.8	18.4	20.5	
	Class II div 2	20.5	3.2	19.3	21.7	
	Class III	19.6	3.3	18.3	20.8	
	Total	19.7	2.8	19.2	20.3	
Posterior facial height (mm)	Class I	70.1	4.0	68.6	71.6	0.000
	Class II div 1	64.8	6.3	62.4	67.3	
	Class II div 2	70.9	4.7	69.1	72.7	
	Class III	66.3	4.6	64.5	68.1	
	Total	68.0	5.5	67.0	69.1	
(A-A') (mm)	Class I	13.1	1.9	12.4	13.9	0.272
	Class II div 1	13.9	3.7	12.4	15.4	
	Class II div 2	13.2	3.0	12.1	14.4	
	Class III	14.7	4.0	13.1	16.2	
	Total	13.7	3.3	13.1	14.3	
(Pr-A') (mm)	Class I	19.2	4.0	17.7	20.7	0.000
	Class II div 1	14.8	2.6	13.8	15.8	
	Class II div 2	15.3	4.1	13.7	16.9	
	Class III	14.0	3.0	12.9	15.2	
	Total	15.8	4.0	15.1	16.6	
(Sti-Me') (mm)	Class I	40.7	3.5	39.3	42.1	0.002
	Class II div 1	38.7	6.2	36.3	41.1	
	Class II div 2	43.3	5.0	41.4	45.2	
	Class III	43.2	4.9	41.3	45.1	
	Total	41.5	5.3	40.5	42.5	
(B-B') (mm)	Class I	9.8	1.4	9.2	10.3	0.092
	Class II div 1	10.3	1.6	9.7	10.9	
	Class II div 2	9.5	2.0	8.7	10.3	
	Class III	10.6	1.9	9.8	11.3	
	Total	10.0	1.8	9.7	10.4	

(Pog-Pog') (mm)	Class I	10.4	2.1	9.6	11.2	0.085
	Class II div 1	11.2	2.4	10.3	12.2	
	Class II div 2	10.7	1.6	10.1	11.3	
	Class III	11.7	2.1	10.9	12.5	
	Total	11.0	2.1	10.6	11.4	

Table IV-3: *One- way ANOVA results*

Appendix V

CASE #	SEX	AGE	Malocclusion	Country of origin	P	CB	ULF	Com	LLF
1	F	12	Class I	Scotland	1	3	1	1	2
2	M	13	Class I	Scotland	2	2	1	1	2
3	M	12	Class I	Scotland	2	2	1	2	2
4	M	14	Class I	Scotland	1	2	2	1	2
5	F	14	Class I	Scotland	1	2	1	1	2
6	M	13	Class I	Scotland	2	1	1	1	2
7	F	12	Class I	Scotland	2	2	1	1	2
8	M	13	Class I	Scotland	2	2	2	2	2
9	F	14	Class I	Scotland	2	1	1	1	2
10	F	14	Class I	Scotland	2	1	1	1	3
11	M	14	Class I	Scotland	2	3	1	1	1
12	M	13	Class I	Scotland	1	3	1	1	1
13	F	13	Class I	Scotland	1	3	1	2	2
14	F	12	Class I	Scotland	2	1	1	2	1
15	F	14	Class III	Scotland	1	3	1	2	2
16	F	11	Class III	Scotland	3	1	1	2	2
17	F	12	Class III	Scotland	1	2	1	1	3
18	M	11	Class III	Scotland	1	2	1	2	2
19	M	14	Class III	Scotland	1	2	1	1	3
20	F	12	Class III	Scotland	2	2	2	3	2
21	M	13	Class III	Scotland	1	3	1	2	2
22	F	12	Class III	Scotland	3	1	1	2	1
23	M	13	Class III	Scotland	1	2	1	2	1
24	F	14	Class III	Scotland	2	3	2	2	2
25	F	14	Class III	Scotland	2	2	1	2	1
26	M	13	Class III	Scotland	2	2	2	3	2
27	M	11	Class III	Scotland	2	2	1	1	1
28	M	13	Class III	Scotland	1	2	1	2	2
29	M	12	Class II div 1	Scotland	1	2	2	2	2
30	F	11	Class II div 1	Scotland	2	2	1	1	2
31	M	14	Class II div 1	Scotland	2	2	1	2	2
32	M	12	Class II div 1	Scotland	1	2	1	2	2
33	M	14	Class II div 1	Scotland	1	2	1	2	2
34	M	11	Class II div 1	Scotland	1	1	2	2	2
35	F	12	Class II div 1	Scotland	1	1	2	2	2
36	F	12	Class II div 1	Scotland	1	2	2	2	3
37	F	14	Class II div 1	Scotland	3	1	2	3	1
38	M	13	Class II div 1	Scotland	3	1	1	1	1
39	M	12	Class II div 1	Scotland	3	2	2	2	1
40	F	11	Class II div 1	Scotland	1	1	2	2	3

CASE #	SEX	AGE	Malocclusion	Country of origin	P	CB	ULF	Com	LLF
41	F	13	Class II div 1	Scotland	1	2	2	2	2
42	F	13	Class II div 1	Scotland	2	2	1	3	1
43	M	14	Class II div 2	Scotland	1	1	2	2	2
44	F	14	Class II div 2	Scotland	2	3	1	1	2
45	M	14	Class II div 2	Scotland	2	3	1	1	3
46	M	12	Class II div 2	Scotland	1	2	1	1	2
47	F	12	Class II div 2	Scotland	1	2	2	2	2
48	M	13	Class II div 2	Scotland	2	2	2	2	2
49	M	12	Class II div 2	Scotland	2	1	1	1	1
50	F	12	Class II div 2	Scotland	1	2	2	3	2
51	F	13	Class II div 2	Scotland	2	2	2	2	1
52	F	14	Class II div 2	Scotland	2	1	1	1	1
53	F	14	Class II div 2	Scotland	2	2	2	2	2
54	F	14	Class II div 2	Scotland	3	2	1	1	1
55	M	11	Class II div 2	Scotland	1	2	2	2	2
56	M	13	Class II div 2	Scotland	2	2	1	1	1
1	F	12	Class I	Jordan	1	3	2	2	2
2	M	14	Class I	Jordan	2	2	1	2	1
3	M	13	Class I	Jordan	1	2	1	1	2
4	F	11	Class I	Jordan	1	2	1	1	2
5	F	12	Class I	Jordan	1	2	2	2	2
6	M	13	Class I	Jordan	1	2	2	3	2
7	M	13	Class I	Jordan	1	2	1	3	2
8	F	14	Class I	Jordan	1	3	1	2	2
9	M	14	Class I	Jordan	2	3	1	2	1
10	F	13	Class I	Jordan	2	2	2	2	2
11	F	13	Class I	Jordan	2	1	1	1	1
12	F	14	Class I	Jordan	2	2	1	2	1
13	M	13	Class I	Jordan	2	3	3	2	2
14	M	14	Class I	Jordan	2	3	3	3	1
15	M	12	Class III	Jordan	1	1	2	2	2
16	M	13	Class III	Jordan	1	1	2	2	3
17	M	13	Class III	Jordan	1	1	2	1	1
18	F	13	Class III	Jordan	1	1	2	1	2
19	M	14	Class III	Jordan	1	1	2	3	3
20	M	11	Class III	Jordan	1	1	2	1	1
21	F	12	Class III	Jordan	1	2	2	1	1
22	M	14	Class III	Jordan	1	1	2	1	1
23	M	14	Class III	Jordan	1	1	2	1	2
24	F	13	Class III	Jordan	1	1	1	1	1
25	F	14	Class III	Jordan	1	1	2	1	1
26	F	11	Class III	Jordan	1	1	2	2	2

CASE #	SEX	AGE	Malocclusion	Country of origin	P	CB	ULF	Com	LLF
27	F	14	Class III	Jordan	1	2	2	1	2
28	F	13	Class III	Jordan	1	1	2	1	2
29	M	14	Class II div 1	Jordan	2	2	2	2	2
30	M	11	Class II div 1	Jordan	2	2	3	2	2
31	F	12	Class II div 1	Jordan	2	1	1	1	1
32	F	13	Class II div 1	Jordan	2	2	1	1	1
33	F	13	Class II div 1	Jordan	1	2	1	3	1
34	M	12	Class II div 1	Jordan	2	2	2	3	1
35	M	13	Class II div 1	Jordan	2	1	1	1	1
36	F	12	Class II div 1	Jordan	2	2	1	2	2
37	F	13	Class II div 1	Jordan	2	3	3	2	2
38	M	13	Class II div 1	Jordan	1	2	1	2	2
39	M	14	Class II div 1	Jordan	2	2	3	3	2
40	F	11	Class II div 1	Jordan	1	2	1	2	1
41	F	11	Class II div 1	Jordan	3	2	2	2	2
42	M	13	Class II div 1	Jordan	1	2	3	2	2
43	F	11	Class II div 2	Jordan	1	3	1	2	2
44	F	13	Class II div 2	Jordan	1	2	2	2	2
45	F	14	Class II div 2	Jordan	2	2	3	3	2
46	F	14	Class II div 2	Jordan	1	2	1	1	2
47	F	13	Class II div 2	Jordan	1	3	1	2	1
48	M	12	Class II div 2	Jordan	1	2	1	1	2
49	M	11	Class II div 2	Jordan	1	2	1	2	2
50	M	13	Class II div 2	Jordan	2	2	1	1	2
51	M	12	Class II div 2	Jordan	2	1	1	1	2
52	M	11	Class II div 2	Jordan	1	3	2	2	2
53	F	12	Class II div 2	Jordan	1	2	1	1	2
54	F	12	Class II div 2	Jordan	1	2	3	3	2
55	M	13	Class II div 2	Jordan	1	2	3	3	1
56	M	14	Class II div 2	Jordan	3	1	2	1	1

Table V-0: *Results of morphological traits score assessments. P: Philtrum shapes, CB: Cupid's bow shapes, ULF: upper lip fullness, Com: commissures' shapes, LLF: Lower lips fullness.*

Chi-square tables
Philtrum shape *malocclusion type

Morphological Traits	Malocclusion type Class I	Class III	Class II div1	Class II div2
Deep groove	(19.7%)	(24.6%)	(36.1%)	(19.7%)
Indentation in the middle	(35.6%)	(19.7%)	(13.3%)	(26.7%)
Smooth philtrum	(0.0%)	(66.7%)	(0.0%)	(33.3%)

Note. χ^2 = 16.221, df = 6. Numbers in parentheses indicate column percentages. p = 0.013

Table V-1: *Results of Chi-square Test for philtrum shape and malocclusion type.*

Cupid bow *philtrum shape

Morphological Traits	Malocclusion type Class I	Class III	Class II div1	Class II div2
Flat	(16.1%)	(45.2%)	(22.6%)	(16.1%)
V-shaped	(22.2%)	(17.5%)	(31.7%)	(28.6%)
U-shaped	(50.0%)	(16.7%)	(5.6%)	(27.8%)

Note. χ^2 = 17.938, df = 6. Numbers in parentheses indicate column percentages. p = 0.006

Table V-2: *Results of Chi-square Test for cupid bow and malocclusion type.*

Lower vermillion fullness *malocclusion type

Morphological Traits	Malocclusion type Class I	Class III	Class II div1	Class II div2
Thin lips	(29.5%)	(29.5%)	(11.4%)	(29.5%)
Average thickness	(22.6%)	(22.6%)	(34.0%)	(20.8%)
Thick lips	(20.0%)	(20.0%)	(33.3%)	(26.7%)

Note. χ^2 = 7.418, df = 6. Numbers in parentheses indicate column percentages. p = 0.284

Table V-3: *Results of Chi-square Test for lower vermillion fullness and malocclusion type.*

Commissures *malocclusion type

Morphological Traits	Malocclusion type Class I	Class III	Class II div1	Class II div2
Upturned	(22.2%)	(27.8%)	(27.8%)	(22.2%)
Straight	(27.9%)	(20.6%)	(23.5%)	(27.9%)
Downturned	(12.5%)	(50.0%)	(25.0%)	(12.5%)

Note. χ^2 = 4.503, df = 6. Numbers in parentheses indicate column percentages. p = 0.609

Table V-4: *Results of Chi-square Test for commissures and malocclusion type.*

Commissures *malocclusion type

Morphological Traits	Malocclusion type Class I	Class III	Class II div1	Class II div2
Upturned	(22.2%)	(27.8%)	(27.8%)	(22.2%)
Straight	(27.9%)	(20.6%)	(23.5%)	(27.9%)
Downturned	(12.5%)	(50.0%)	(25.0%)	(12.5%)

Note. χ^2 = 4.503, df = 6. Numbers in parentheses indicate column percentages. p = 0.609

Table V-5: *Results of Chi-square Test for commissures and malocclusion type.*

Cupid bow *philtrum shape

	Deep groove	Indentation in the middle	Smooth
Flat	(51.6%)	(38.7%)	(9.7%)
V-shaped	(54.0%)	(41.3%)	(4.8%)
U-shaped	(61.1%)	(38.9%)	(0.0%)

Note. χ^2 = 2.324, df = 4. Numbers in parentheses indicate column percentages. p = 0.676

Table V-6: *Results of Chi-square Test for cupid bow and philtrum shape.*

Lower vermillion fullness *philtrum shape

	Deep groove	Indentation in the middle	Smooth
Thin lips	(50.0%)	(43.2%)	(6.8%)
Average thickness	(60.4%)	(35.8%)	(3.8%)
Thick lips	(46.7%)	(46.7%)	(6.7%)

Note. χ^2 = 1.643, df = 4. Numbers in parentheses indicate column percentages. p = 0.801

Table V-7: *Results of Chi-square Test for lower lip fullness and philtrum shape.*

Commissures shape *philtrum shape

	Deep groove	Indentation in the middle	Smooth
Upturned	(33.3%)	(52.8%)	(13.9%)
Straight	(63.2%)	(35.3%)	(1.5%)
Downturned	(54.5%)	(25.0%)	(0.0%)

Note. χ^2 = 14.054, df = 4. Numbers in parentheses indicate column percentages. p = 0.007

Table V-8: *Results of Chi-square Test for commissures shape and philtrum shape.*

Lower vermillion fullness * Cupid bow shape

	Flat	V-shaped	U-shaped
Thin lips	(43.2%)	(45.5%)	(11.4%)
Average thickness	(18.9%)	(58.5%)	(22.6%)
Thick lips	(13.3%)	(80.0%)	(5.6%)

Note. χ^2 = 11.741, df = 4. Numbers in parentheses indicate column percentages. p = 0.019

Table V-9: *Results of Chi-square Test for commissures shape and philtrum shape.*

Shape of commissures * Cupid bow shape

	Flat	V-shaped	U-shaped
Upturned	(41.7%)	(44.4%)	(13.9%)
Straight	(17.6%)	(64.7%)	(17.6%)
Downturned	(50.0%)	(37.5%)	(12.5%)

Note. χ^2 = 8.989, df = 4. Numbers in parentheses indicate column percentages. p = 0.061

Table V-10: *Results of Chi-square Test for commissures shape and cupid bow shape.*

Lower vermillion fullness * Commissures shape

	Thin lips	Average	Thick
Upturned	(52.8%)	(30.6%)	(16.7%)
Straight	(30.9%)	(57.4%)	(11.8%)
Downturned	(50.0%)	(37.5%)	(12.5%)

Note. χ^2 = 7.299, df = 4. Numbers in parentheses indicate column percentages. p = 0.121

Table V-11: *Results of Chi-square Test for commissures shape and lower lips fullness.*

Philtrum shape * Lower vermillion fullness

	Thin lips	Average	Thick
Deep groove	(36.1%)	(52.5%)	(11.5%)
Indentation in the middle	(42.2%)	(42.2%)	(15.6%)
Smooth Philtrum	(50.0%)	(33.3%)	(16.7%)

Note. χ^2 = 1.643, df = 4. Numbers in parentheses indicate column percentages. p = 0.801

Table V-12: *Results of Chi-square Test for philtrum shape and lower lips fullness.*

Cupid's bow shape * Lower vermillion fullness

	Thin lips	Average	Thick
Flat	(61.3%)	(32.3%)	(6.5%)
V-shaped	(31.7%)	(49.2%)	(19.0%)
U-shaped	(27.8%)	(66.7%)	(5.6%)

Note. χ^2 = 11.741, df = 4. Numbers in parentheses indicate column percentages. p = 0.019

Table V-13: *Results of Chi-square Test for cupid bow shape and lower lips fullness.*

Upper vermillion fullness *malocclusion type

Country of origin = Jordan

	Malocclusion type			
Morphological Traits	Class I	Class III	Class II div1	Class II div2
Thin lips	(33.3%)	(4.2%)	(29.2%)	(33.3%)
Average thickness	(17.4%)	(56.5%)	(13.0%)	(13.0%)
Thick lips	(22.2%)	(0.0%)	(44.4%)	(33.3%)

Note. χ^2 = 21.860, df = 6. Numbers in parentheses indicate column percentages. p = 0.001

Table V-14: *Results of Chi-square Test for upper vermillion fullness (Jordan) and malocclusion type.*

Upper vermillion fullness *malocclusion type

Country of origin = Scotland

	Malocclusion type			
Morphological Traits	Class I	Class III	Class II div1	Class II div2
Thin lips	(33.3%)	(30.6%)	(16.7%)	(19.4%)
Average thickness	(10.0%)	(15.0%)	(40.0%)	(35.0%)
Thick lips	(0.0%)	(0.0%)	(0.0%)	(0.0%)

Note. χ^2 = 8.089, df = 3. Numbers in parentheses indicate column percentages. p = 0.044.

Table V-15: *Results of Chi-square Test for upper vermillion fullness (Scotland) and malocclusion type.*

Philtrum shape * Upper vermillion fullness

Country of origin = Jordan

	Thin lips	Average	Thick
Deep groove	(58.3%)	(78.3%)	(33.3%)
Indentation in the middle	(41.7%)	(13.0%)	(66.7%)
Smooth Philtrum	(0.0%)	(8.7%)	(0.0%)

Note. χ^2 = 11.299, df = 4. Numbers in parentheses indicate column percentages. p = 0.023

Table V- 16: *Results of Chi-square Test for philtrum shape and upper lips fullness.*

Cupid's bow shape * Upper vermillion fullness

Country of origin = Jordan

	Flat	V-shaped	U-shaped
Thin lips	(20.8%)	(62.5%)	(16.7%)
Average	(52.2%)	(39.1%)	(8.7%)
Thick lips	(0.0%)	(66.7%)	(33.3%)

Note. χ^2 = 11.048, df = 4. Numbers in parentheses indicate column percentages. p = 0.026

Table V-17: *Results of Chi-square Test for cupid bow shape and upper lips fullness.*

Lower vermillion fullness * Upper vermillion fullness

Country of origin = Jordan

	Lower vermillion fullness		
Upper vermillion	Thin lips	Average	Thick lips
Thin lips	(50.0%)	(41.7%)	(8.3%)
Average	(43.5%)	(43.5%)	(13.0%)
Thick lips	(0.0%)	(44.4%)	(55.6%)

Note. χ^2 = 13.035, df = 4. Numbers in parentheses indicate column percentages. p = 0.011

Table V-18: *Results of Chi-square Test for lower lips fullness and upper lips fullness.*

Upper vermillion fullness * Commissures

Country of origin = Jordan

	Upturned	Straight	Downturned
Thin lips	(45.8%)	(54.2%)	(0.0%)
Average	(30.4%)	(60.9%)	(8.7%)
Thick lips	(22.2%)	(77.8%)	(0.0%)

Note. χ^2 = 4.797, df = 4. Numbers in parentheses indicate column percentages. p = 0.309

Table V-19: *Results of Chi-square Test for cupid bow shape and upper lips fullness.*

Philtrum shape * Upper vermillion fullness

Country of origin = Scotland

	Deep groove	indentation	Smooth
Thin lips	(38.9%)	(55.6%)	(5.6%)
Average thickness	(60.0%)	(30.0%)	(10.0%)

Note. χ^2 = 3.398, df = 2. Numbers in parentheses indicate column percentages. p = 0.183

Table V-20: *Results of Chi-square Test for philtrum shape and upper lips fullness.*

Cupid's bow shape * Upper vermillion fullness

Country of origin = Scotland

	Flat	V-shaped	U-shaped
Thin lips	(25.0%)	(52.8%)	(22.2%)
Average thickness	(25.0%)	(70.0%)	(5.0%)

Note. χ^2 = 3.020, df = 2. Numbers in parentheses indicate column percentages. p = 0.221

Table V-21: *Results of Chi-square Test for cupid bow shape and upper lips fullness.*

Lower vermillion fullness * Upper vermillion fullness

Country of origin = Scotland

	Lower vermillion fullness		
Upper vermillion	Thin lips	Average	Thick lips
Thin lips	(58.3%)	(38.9%)	(2.8%)
Average	(5.0%)	(75.0%)	(20.0%)

Note. χ^2 = 16.818, df = 2. Numbers in parentheses indicate column percentages. p < 0.001

Table V- 22: *Results of Chi-square Test for lower lips fullness and upper lips fullness.*

Upper vermillion fullness * Commissures

Country of origin = Scotland

	Upturned	Straight	Downturned
Thin lips	(36.1%)	(52.8%)	(11.1%)
Average	(15.0%)	(75.0%)	(10.0%)

Note. χ^2 = 3.066, df = 2. Numbers in parentheses indicate column percentages. p = 0.216

Table V-23: *Results of Chi-square Test for cupid bow shape and upper lips fullness.*

GMM Table

Variable	Procrustes sums of squares	Tangent sums of squares
Jordan	1.641	1.283
Scotland	1.600	1.259
Class I	0.226	0.223
Class II div 1	1.045	1.016
Class II div 2	0.774	0.757
Class III	0.897	0.880
Male	1.601	1.561
Female	1.370	1.343

***Table V-24**: Size variation measured by Procrustes sums of squares assessed in different malocclusion classes for both the Scottish and Jordanian data, and separately for ma*

PCA

PC#	Eigenvalues	% Variance	Cumulative %
1.	0.00550090	38.205	38.205
2.	0.00334843	23.256	61.460
3.	0.00087694	6.091	67.551
4.	0.00077459	5.380	72.931
5.	0.00062240	4.323	77.253
6.	0.00046183	3.208	80.461
7.	0.00038005	2.640	83.100
8.	0.00034285	2.381	85.482
9.	0.00027662	1.921	87.403
10.	0.00019846	1.378	88.781
11.	0.00017453	1.212	89.993
12.	0.00015917	1.105	91.099
13.	0.00012830	0.891	91.990
14.	0.00011439	0.794	92.784
15.	0.00010725	0.745	93.529
16.	0.00010366	0.720	94.249
17.	0.00009408	0.653	94.902
18.	0.00007325	0.509	95.411
19.	0.00006041	0.420	95.831
20.	0.00005451	0.379	96.209
21.	0.00005328	0.370	96.579
22.	0.00005136	0.357	96.936

***Table V-25:** Per cent variance and cumulative variance explained by first 22 PCs (total number of PCs: 46).*

“The output table (Table V-25) of PCA in the Results window contains the following information:

- **Eigenvalues:** For each PC, the corresponding eigenvalue is given in the original units (e.g. units of Procrustes variance), as a percentage of the total variance and as the cumulative percentage of total variance.
- **Total variance:** The total variance is the sum of the variances across all coordinates in shape space (the trace of the covariance matrix) or, equivalently, the sum of all eigenvalues in the PCA.
- **Indices of morphological integration:** These include the **variance of the eigenvalues** in the original units (of squared Procrustes distance), which can range from 0 (for no integration at all) to a maximum that is specific to each dataset. The second index is the **variance of eigenvalues scaled by the total variance**, which can range from 0 to $(p – 1)/p^2$. The third index is the **variance of eigenvalues scaled by the total variance and number of variables**, which can range from 0 to a maximum of 1. (These statistics are only displayed for PCAs done in version 1.06c or higher.)
- **PC coefficients:** The PC coefficients (eigenvectors) are given in tabular form (if the data permit, a graphical representation is given by the graph of **PC shape changes** in the Graphics window).” (Klingenberg, 2011).

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